Annex to

World Limits Model (WoLiM) 1.5
Model Documentation

Model equations

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This document collates the equations and commentaries of the WoLiM 1.5 model by views of the model in VENSIM.

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1. SOCIOE – GDPpc & population

dollars to Tdollars=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C15')

Units: Dmnl

Conversion from dollars to Tdollars (1 T$ = 1e12 $).

GDP[scenarios]=

GDPcap[scenarios]*Population[scenarios]/dollars to Tdollars

Units: Tdollars/Year

Global Domestic Product.

GDP delayed 1yr[scenarios]= DELAY FIXED (

GDP[scenarios], 1, 39.435)

Units: Tdollars/Year

GDP projection delayed 1 year. Data from World Bank -->

GDP(1989)=39.435 T$ US2011. .

GDP growth rate[scenarios]=

-1+GDP[scenarios]/GDP delayed 1yr[scenarios]

Units: Dmnl

GDP growth rate.

GDPcap[scenarios]= INTEG (

GDPcap variation[scenarios],

initial GDPcap)

Units: dollars/(people*Year)

GDP per capita projection. Initial value from WorldBank in 1990

(2011 UST$)

GDPcap variation[scenarios]=

IF THEN ELSE(Time>2015,GDPcap[scenarios]*P GDPcap[scenarios], growth historic GDPpc

)

Units: dollars/Year/people

GDP per capita growth. (Historic data from 1990-2010; projection

2011-2100) 2011 UST$

growth historic pop=

IF THEN ELSE(Time<2015, Historic pop(Time+1)-Historic pop(Time), 0)

Units: people/Year

Population historic growth.

growth historic GDPpc=

IF THEN ELSE(Time<2015, Historic GDP(Time+1)*dollars to Tdollars/Historic pop (Time+1)-Historic GDP(Time)*dollars to Tdollars/Historic pop(Time), 0)

Units: 1/Year

Historic GDP growth.

Historic GDP(

GET XLS LOOKUPS('inputs.xlsx', 'Constants', '25', 'C27'))

Units: trillion$

Historic GDP in trillion 2011$ (1990-2015). Estimated from data from World bank (from current and 2010$ GDP values).

Historic pop(

GET XLS LOOKUPS('inputs.xlsx', 'Constants', '25', 'C28'))

Units: people

Historic population (1990-2015). Ref: World bank.

initial GDP=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C27')

Units: billion$

Initial value from WorldBank in 1990 (2011 UST$).

initial GDPcap=

initial GDP*dollars to Tdollars/initial population

Units: dollars/people

GDP per capita in the year 1990.

initial population=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C28')

Units: people

Initial value from WorldBank in 1990.

```
P GDPcap[BAU]:INTERPOLATE::=
        GET XLS DATA('inputs.xlsx', 'BAU', '4', 'A5')
P GDPcap[SCEN1]:INTERPOLATE::=
                GET XLS DATA('inputs.xlsx', 'SCEN1', '4', 'A5')
P GDPcap[SCEN2]:INTERPOLATE::=
                GET XLS DATA('inputs.xlsx', 'SCEN2', '4', 'A5')
P GDPcap[SCEN3]:INTERPOLATE::=
                GET XLS DATA('inputs.xlsx', 'SCEN3', '4', 'A5')
P GDPcap[SCEN4]:INTERPOLATE::=
                GET XLS DATA('inputs.xlsx', 'SCEN4', '4', 'A5')
P GDPcap[User defined]:INTERPOLATE::=
                GET XLS DATA('inputs.xlsx', 'User defined', '4', 'A5')
        Units: 1/Year
        GDP per capita projection annual growth from 2015. See Technical
                        report.

P growth pop[BAU]:INTERPOLATE::=
        GET XLS DATA('inputs.xlsx', 'BAU', '7', 'A8')
P growth pop[SCEN1]:INTERPOLATE::=
                GET XLS DATA('inputs.xlsx', 'SCEN1', '7', 'A8')
P growth pop[SCEN2]:INTERPOLATE::=
                GET XLS DATA('inputs.xlsx', 'SCEN2', '7', 'A8')
P growth pop[SCEN3]:INTERPOLATE::=
                GET XLS DATA('inputs.xlsx', 'SCEN3', '7', 'A8')
P growth pop[SCEN4]:INTERPOLATE::=
                GET XLS DATA('inputs.xlsx', 'SCEN4', '7', 'A8')
P growth pop[User defined]:INTERPOLATE::=
                GET XLS DATA('inputs.xlsx', 'User defined', '7', 'A8')
        Units: 1/Year
        Annual population growth. UN projections in their medium
                        scenario (Medium fertility variant)

pop variation[scenarios]=
        IF THEN ELSE(Time<2015, growth historic pop, Population[scenarios]*P growth pop
[scenarios])
Units: people/Year
Population growth. (Historic data from 1990-2010; projection
```

2011-2100) 2011 UST$

Population[scenarios]= INTEG (
pop variation[scenarios],
initial population)
Units: people
Population projection.

2. Elec – Electricity demand

"'a' historical I-ELEC":INTERPOLATE::=
GET XLS DATA('inputs.xlsx', 'Constants', '25', 'C30')
Units: Dmnl
Historical annual electricity consumption intensity improvement,
"a" parameter in 1980-2010: a=I(t)/I(t-1).

"'a' I-ELEC projection"[BAU]=
GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C10')
"'a' I-ELEC projection"[SCEN1]=
GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C10')
"'a' I-ELEC projection"[SCEN2]=
GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C10')
"'a' I-ELEC projection"[SCEN3]=
GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C10')
"'a' I-ELEC projection"[SCEN4]=
GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C10')
"'a' I-ELEC projection"[User defined]=
GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C10')
Units: Dmnl
Evolution depending on the scenario of the "a" parameter, which
represents the annual PE intensity improvement of the sector,
i.e. indirectly the Annual Efficiency Improvements (a=1-AEI),
Constant value over time.

"Adapt 'a' I-ELEC"[scenarios]=
IF THEN ELSE(Time>2010,IF THEN ELSE(Time<"year 'a-ELEC' projected reached"
[scenarios],1+

("'a' I-ELEC projection"[scenarios]-1)*(Time-2010)/("year 'a-ELEC' projected reached"
[scenarios]-2010) , "'a' I-ELEC projection"
[scenarios]) , "'a' historical I-ELEC")

Units: Dmnl

Smoothing transition for the parameter "a" between the
historical trends and the projected trend. The projected trend
is reached at "year 'a-sector' projected reached".

Dem Elec gen TWe[scenarios]=

Total FE Elec demand TWh[scenarios]*TWe per TWh

Units: TWe

Electricity demand (TWe).

EJ per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C5')

Units: EJ/TWh

Unit conversion (3.6 EJ=1000 TWh)

Electrical distribution losses EJ[scenarios]=

Electrical distribution losses TWh[scenarios]*EJ per TWh

Units: EJ/Year

Electical distribution losses (EJ)

Electrical distribution losses TWh[scenarios]=

Total FE Elec demand TWh[scenarios]*share elec distribution losses

Units: TWh

Electrical distribution losses (TWh)

FE demand Elec consum 1989 TWh=

10127.8

Units: TWh

In 1989 electric energy consumption was 10127.85 TWh.

FE demand Elec consum delayed 1yr[scenarios]= DELAY FIXED (

FE demand Elec consum TWh[scenarios], 1 , FE demand Elec consum 1989 TWh)

Units: TWh

Electricity consumption (TWh) delayed 1 year

FE demand Elec consum TWh[scenarios]=

GDP[scenarios]*"I-ELEC"[scenarios]

Units: TWh

Electricity consumption (TWh)

FE demand Elec EJ[scenarios]=

FE demand Elec consum TWh[scenarios]*EJ per TWh

Units: EJ

Electricity consumption (final energy, EJ)

GDP[scenarios]=

GDPcap[scenarios]*Population[scenarios]/dollars to Tdollars

Units: Tdollars/Year

Global Domestic Product.

GDP delayed 1yr[scenarios]= DELAY FIXED (

GDP[scenarios], 1, 39.435)

Units: Tdollars/Year

GDP projection delayed 1 year. Data from World Bank -->

GDP(1989)=39.435 T$ US2011. .

"I-ELEC delayed 1yr"[scenarios]=

FE demand Elec consum delayed 1yr[scenarios]/GDP delayed 1yr[scenarios]

Units: TWh/Tdollars

Electricity consumption intensity delayed 1 year

"I-ELEC"[scenarios]=

IF THEN ELSE(Time>2010, "I-ELEC min"[scenarios

]+("I-ELEC(t=0), i.e. 2010"-"I-ELEC min"[scenarios])*"Adapt 'a' I-ELEC"[scenarios

]^"t I-ELEC"[scenarios],"'a' historical I-ELEC"*"I-ELEC delayed 1yr"[scenarios

])

Units: TWh/Tdollars

Electricity consumption intensity. Equation as a physical

indicator as proposed by (Schenk and Moll, 2007)

I_t=I_min+(I_(t=0)-I_min)·a^t

"I-ELEC(t=0), i.e. 2010"=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C101')

Units: TWh/Tdollars

Value of the primary energy intensity of the Industry and Buildings sector in the initial year (2010) to apply Schenk and Moll, 2007 equation.

"I-ELEC min"[scenarios]=

"I-ELEC(1990)"*pct Imin[scenarios]

Units: TWh/Tdollars

"Ielec min" is a horizontal asymptote that represents the minimum value of the future electricity energy intensity (Schenk and Moll equation).

"I-ELEC(1990)"=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C104')

Units: EJ/Tdollars

Value of the primary energy intensity of the Electricity sector in 1990.

increase Elec demand for Transp TWh[scenarios]=

increase Elec demand EVs TWh[scenarios]

Units: TWh

Additional electricity demand by alternative transport (BEV & HEV). Since in this model version there are not other alternatives modes of transport that consume electricity (e.g. train), this variable matches with "increase E EV TWh".

pct Imin[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C16')

pct Imin[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C16')

pct Imin[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C16')

pct Imin[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C16')

pct Imin[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C16')

pct Imin[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C16')

Units: Dmnl

Percentage defining the minimum energy intensity (Schenk and Moll equation). The same value is assumed for all sectors. If this percentage is set to 0, then the equation of Schenk and Moll equates the conventional expression of energy intensity.

PE losses related to Elec Transp[scenarios]=

(increase Elec demand for Transp TWh[scenarios]*EJ per TWh/Total FE Elec demand EJ [scenarios])*Total electrical losses EJ[scenarios]

Units: EJ/Year

Allocation of the electricity losses (generation + distribution) corresponding to the alternative modes of transport using electricity ("increase Elec demand for Transp").

share elec distribution losses=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C54')

Units: Dmnl

Share of electrical distribution losses in relation to electricity consumption. We define these losses at around 9.5% following historical data.

"t I-ELEC"[scenarios]=

Time dmnl[scenarios](Time)-2010

Units: Dmnl

Time (Schenk and Moll equation), taking as reference the last year of "'a' historical I-IB intensity" (2010).

Time dmnl[scenarios](

[(1990,1990)-(2100,2100)],(1990,1990),(1991,1991),(1992,1992),(1993,1993),(1994,1994),(1995,1995),(1996,1996),(1997,1997),(1998,1998),(1999,1999),(2000,2000),(2001,2001),(2002,2002),(2003,2003),(2004,2004),(2005,2005),(2006,2006),(2007,2007),(2008,2008),(2009,2009),(2010,2010),(2011,2011),(2012,2012),(2013,2013),(2014,2014),(2015,2015),(2016,2016),(2017,2017),(2018,2018),(2019,2019),(2020,2020),(2021,2021),(2022,2022),(2023,2023),(2024,2024),(2025,2025

),(2026,2026),(2027,2027),(2028,2028),(2029,2029),(2030,2030),(2031,2031),(
2032,2032),(2033,2033),(2034,2034),(2035,2035),(2036,2036),(2037,2037),(2038
,2038),(2039,2039),(2040,2040),(2041,2041),(2042,2042),(2043,2043),(2044,2044
),(2045,2045),(2046,2046),(2047,2047),(2048,2048),(2049,2049),(2050,2050),(
2051,2051),(2052,2052),(2053,2053),(2054,2054),(2055,2055),(2056,2056),(2057
,2057),(2058,2058),(2059,2059),(2060,2060),(2061,2061),(2062,2062),(2063,2063
),(2064,2064),(2065,2065),(2066,2066),(2067,2067),(2068,2068),(2069,2069),(
2070,2070),(2071,2071),(2072,2072),(2073,2073),(2074,2074),(2075,2075),(2076
,2076),(2077,2077),(2078,2078),(2079,2079),(2080,2080),(2081,2081),(2082,2082
),(2083,2083),(2084,2084),(2085,2085),(2086,2086),(2087,2087),(2088,2088),(
2089,2089),(2090,2090),(2091,2091),(2092,2092),(2093,2093),(2094,2094),(2095
,2095),(2096,2096),(2097,2097),(2098,2098),(2099,2099),(2100,2100))

Units: Dmnl

Vector that assigns for every year the number of that same year.

Total electrical losses EJ[scenarios]=

Elec gen related losses EJ[scenarios]+Electrical distribution losses EJ[scenarios
]

Units: EJ/Year

Total losses from electricity generation (generation +
distribution).

Total FE Elec demand EJ[scenarios]=

Total FE Elec demand TWh[scenarios]*EJ per TWh

Units: EJ/Year

Electricity demand generation (final energy, includes
distribution losses).

Total FE Elec demand TWh[scenarios]=

(FE demand Elec consum TWh[scenarios]+increase Elec demand for Transp TWh[
scenarios])*(1+share elec distribution losses)

Units: TWh/Year

Total final energy electricity demand (TWh). It includes new
electric uses (e.g. EV & HEV) and electrical distribution losses.

TWe per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C7')

Units: TWe/(TWh/Year)

Unit conversion (1 TWe=8760 TWh per year)

"year 'a-ELEC' projected reached"[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C11')

"year 'a-ELEC' projected reached"[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C11')

"year 'a-ELEC' projected reached"[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C11')

"year 'a-ELEC' projected reached"[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C11')

"year 'a-ELEC' projected reached"[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C11')

"year 'a-ELEC' projected reached"[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C11')

Units: Year

Year when the projected improvement of primary energy intensity of the sector ("a-sector" value) is reached.

3. ELEC – Total energy from electric RES

Demand Elec NRE TWh[scenarios]=

MAX(0, Total FE Elec demand TWh[scenarios]-FE Elec generation from RES TWh [scenarios])

Units: TWh/Year

The model assigns priority to RES generation to cover the electricity demand.

EJ per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C5')

Units: EJ/TWh

Unit conversion (3.6 EJ=1000 TWh)

FE Elec generation from BioW TWh[scenarios]=

BioW TWe[scenarios]/TWe per TWh

Units: TWh/Year

Annual electricity generation.

FE Elec generation from geot TWh[scenarios]=

"geot-elec TWe"[scenarios]/TWe per TWh

Units: TWh/Year

Annual electricity generation.

FE Elec generation from hydro TWh[scenarios]=

hydro TWe[scenarios]/TWe per TWh

Units: TWh/Year

Annual electricity generation.

FE Elec generation from oceanic TWh[scenarios]=

oceanic TWe[scenarios]/TWe per TWh

Units: TWh/Year

Annual electricity generation.

FE Elec generation from offshore wind TWh[scenarios]=

offshore wind TWe[scenarios]/TWe per TWh

Units: TWh/Year

Annual electricity generation.

FE Elec generation from onshore wind TWh[scenarios]=

onshore wind TWe[scenarios]/TWe per TWh

Units: TWh/Year

Annual electricity generation.

FE Elec generation from RES EJ[scenarios]=

FE Elec generation from RES TWh[scenarios]*EJ per TWh

Units: EJ/Year

FE Elec generation from RES TWh[scenarios]=

FE Elec generation from BioW TWh[scenarios]+FE Elec generation from geot TWh [scenarios]+FE Elec generation from hydro TWh[scenarios]+FE Elec generation from solar TWh [scenarios]+FE Elec generation from onshore wind TWh[scenarios]+FE Elec generation from offshore wind TWh [scenarios]+FE Elec generation from oceanic TWh[scenarios]

Units: TWh/Year

Final energy electricity generation from RES (TWh).

FE Elec generation from solar TWh[scenarios]=

solar TWe[scenarios]/TWe per TWh

Units: TWh/Year

Annual electricity generation.

MToe per EJ=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C6')

Units: MToe/EJ

Unit conversion (1000 Mtoe=41.868 EJ)

max BioW TWe[scenarios]=

max BioW without delivered Bio Elec TWe[scenarios]+delivered BioE Electricity TWe [scenarios]

Units: TWe

Techno-ecological potential of biomass&waste. This potential is dynamic and dependant on the potential assigned for bioenergy, and the assumed share for electricity ("delivered BioE Electricity") (1 TWe = 8760 TWh in one year).

"max geot-elec TWe"[scenarios]=

Geothermal PE potential TWth[scenarios]*share geot for elec[scenarios]*Efficiency conversion geot PE to Elec

Units: TWe

Techno-ecological potential of electric geothermal (1 TWe = 8760 TWh in one year). We assume that the global potential of 0.2 TWe is shared at 50% for heat and electric purposes. See Technical Report.

max hydro TWe[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C24')

max hydro TWe[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C24')

max hydro TWe[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C24')

max hydro TWe[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C24')

max hydro TWe[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C24')

max hydro TWe[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C24')

Units: TWe

Techno-ecological potential of hydro (1 TWe = 8760 TWh in one year).

max oceanic TWe[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C27')

max oceanic TWe[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C27')

max oceanic TWe[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C27')

max oceanic TWe[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C27')

max oceanic TWe[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C27')

max oceanic TWe[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C27')

Units: TWe

Techno-ecological potential of oceanic (1 TWe = 8760 TWh in one year).

max offshore wind TWe[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C29')

max offshore wind TWe[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C29')

max offshore wind TWe[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C29')

max offshore wind TWe[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C29')

max offshore wind TWe[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C29')

max offshore wind TWe[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C29')

Units: TWe

Techno-ecological potential of offshore wind (1 TWe = 8760 TWh in one year).

max onshore wind TWe[BAU]=
GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C28')
max onshore wind TWe[SCEN1]=
GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C28')
max onshore wind TWe[SCEN2]=
GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C28')
max onshore wind TWe[SCEN3]=
GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C28')
max onshore wind TWe[SCEN4]=
GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C28')
max onshore wind TWe[User defined]=
GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C28')
Units: TWe
Techno-ecological potential of onshore wind (1 TWe = 8760 TWh in one year).

max solar on land TWe[scenarios]=
max solar on land Mha[scenarios]*power density solar
Units: TWe
Techno-ecological potential of solar on land (All technologies aggregated). This potential is dependant on the assumed land availability for solar power plants ("max solar MHa") and the power density (1 TWe = 8760 TWh in one year).

max total RES for electricity[scenarios]=
max BioW TWe[scenarios]+"max geot-elec TWe"[scenarios]+max hydro TWe[scenarios]+max oceanic TWe[scenarios]+max offshore wind TWe[scenarios]+max onshore wind TWe[scenarios]+max solar on land TWe[scenarios]
Units: TWe

PE BioW for Elec generation EJ[scenarios]=
FE Elec generation from BioW TWh[scenarios]*EJ per TWh/efficiency conversion bioE residues to Elec
Units: EJ/Year
Annual primary energy to generate electricity (Direct Equivalent

Method).

PE Elec generation from RES EJ[scenarios]=

PE BioW for Elec generation EJ[scenarios]+(PE geot for Elec generation EJ[
scenarios]+PE hydro for Elec generation EJ
[scenarios]+PE oceanic for Elec generation EJ[scenarios]+PE solar for Elec generation EJ
[scenarios]+PE onshore wind for Elec generation EJ
[scenarios]+PE offshore wind for Elec generation EJ[scenarios])/RES to fossil accounting
[scenarios]

Units: EJ/Year

Primary energy from RES electricity generation. For all sources
excepting "Bio" the factor "RES to fossil accounting" is applied
for the equivalent primary energy.

PE Elec generation from RES Mtoe[scenarios]=

PE Elec generation from RES EJ[scenarios]*MToe per EJ

Units: MToe/Year

Primary energy from RES electricity generation.

PE geot for Elec generation EJ[scenarios]=

FE Elec generation from geot TWh[scenarios]*EJ per TWh

Units: EJ/Year

Annual primary energy to generate electricity (Direct Equivalent
Method).

PE hydro for Elec generation EJ[scenarios]=

FE Elec generation from hydro TWh[scenarios]*EJ per TWh

Units: EJ/Year

Annual primary energy to generate electricity (Direct Equivalent
Method).

PE oceanic for Elec generation EJ[scenarios]=

FE Elec generation from oceanic TWh[scenarios]*EJ per TWh

Units: EJ/Year

Annual primary energy to generate electricity (Direct Equivalent
Method).

PE offshore wind for Elec generation EJ[scenarios]=

FE Elec generation from offshore wind TWh[scenarios]*EJ per TWh

Units: EJ/Year

Annual primary energy to generate electricity (Direct Equivalent Method).

PE onshore wind for Elec generation EJ[scenarios]=

FE Elec generation from onshore wind TWh[scenarios]*EJ per TWh

Units: EJ/Year

Annual primary energy to generate electricity (Direct Equivalent Method).

PE solar for Elec generation EJ[scenarios]=

FE Elec generation from solar TWh[scenarios]*EJ per TWh

Units: EJ/Year

Annual primary energy to generate electricity (Direct Equivalent Method).

remaining potential RES for electricity[scenarios]=

(max total RES for electricity[scenarios]-FE Elec generation from RES TWh[scenarios]*TWe per TWh)/max total RES for electricity[scenarios]

Units: **undefined**

Remaining potential available as a fraction of unity.

RES to fossil accounting[scenarios]=

1

Units: Dmnl

There are different methods to report primary energy. If=1, it corresponds with the direct equivalent method which counts one unit of secondary energy provided from non-combustible sources as one unit of primary energy, that is, 1 kWh of (useful) electricity or heat is accounted for as 1 kWh = 3.6 MJ of primary energy. For more information see Annex II of (IPCC, 2011).

share Elec demand covered by RES[scenarios]=

IF THEN ELSE(Total FE Elec demand TWh[scenarios]>0, (FE Elec generation from RES TWh [scenarios]/Total FE Elec demand TWh[scenarios])*100, 0.5)

Units: Dmnl

Share of the electricity demand covered by RES. Condition to

avoid error when the denominator is zero (0.5 is an arbitrary

value).

share Elec generation covered by RES[scenarios]=

FE Elec generation from RES TWh[scenarios]/Total FE Elec generation TWh[scenarios

]

Units: Dmnl

Share of the electricity generation covered by RES.

Total FE Elec demand TWh[scenarios]=

(FE demand Elec consum TWh[scenarios]+increase Elec demand for Transp TWh[

scenarios])*(1+share elec distribution losses)

Units: TWh/Year

Total final energy electricity demand (TWh). It includes new

electric uses (e.g. EV & HEV) and electrical distribution losses.

Total FE Elec generation TWh[scenarios]=

FE Elec generation from NRE TWh[scenarios]+FE Elec generation from RES TWh

[scenarios]

Units: TWh/Year

Total final energy electricity generation (fossil fuels, nuclear

& renewables) (TWh).

TWe per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C7')

Units: TWe/(TWh/Year)

Unit conversion (1 TWe=8760 TWh per year)

4. ELEC – Share of electricity supply by fossil fuel

demand Elec gas and coal TWh[scenarios]=

MAX(Demand Elec NRE without liquids TWh[scenarios]-FE nuclear Elec generation TWh

[scenarios], 0)

Units: TWh/Year

The model assigns priority to RES, oil (exogenous evolution) and

nuclear generation (depending on the selected nuclear scenario)
among the non-renewable electricity generation.

Demand Elec NRE TWh[scenarios]=
MAX(0, Total FE Elec demand TWh[scenarios]-FE Elec generation from RES TWh
[scenarios])
Units: TWh/Year
The model assigns priority to RES generation to cover the
electricity demand.

Demand Elec NRE without liquids TWh[scenarios]=
MAX(Demand Elec NRE TWh[scenarios]-FE demand liquids for Elec TWh[scenarios
], 0)
Units: TWh/Year
Among the NRE, we assign priority to generation of oil from
electricity since it is an exogenous assumption for all
scenarios.

efficiency coal for electricity=
GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C46')
Units: Dmnl
Efficiency of coal gas power centrals. Stable trend between 1971
and 2014 (IEA Balances), average of the period.

efficiency gas for electricity= INTEG (
improvement efficiency gas for electricity,
initial efficiency gas for electricity)
Units: Dmnl
Efficiency of the gas power centrals.

Efficiency improv gas for electricity=
GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C52')
Units: Dmnl
Annual efficiency improvement in percentage of the gas power
centrals for electricity production.

efficiency liquids for electricity=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C45')

Units: Dmnl

Efficiency of oil in electricity power centrals. Stable trend between 1971 and 2014 (IEA Balances), average of the period.

EJ per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C5')

Units: EJ/TWh

Unit conversion (3.6 EJ=1000 TWh)

FE demand coal for Elec TWh[scenarios]=

share coal for Elec[scenarios]*demand Elec gas and coal TWh[scenarios]

Units: TWh/Year

Final energy demand of coal (EJ) for electricity consumption.

FE demand gas for Elec TWh[scenarios]=

"share gas/(coal+gas) for Elec"[scenarios]*demand Elec gas and coal TWh[scenarios
]

Units: TWh/Year

Final energy demand of natural gas for electricity consumption (TWh).

FE demand liquids for Elec TWh[scenarios]=

share liquids for Elec[scenarios]*Total FE Elec demand TWh[scenarios]

Units: TWh/Year

Final energy demand of oil to produce electricity.

"future share gas/(coal+gas) for Elec"=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C39')

Units: Dmnl

Assumption for the future share of gas vs. (gas+coal) for electricity generation. Since this share has remained fairly constant since 1990, we assume that the value for the last year (2013) is maintained in the future.

"Hist share gas/(coal+gas) Elec":INTERPOLATE::=

GET XLS DATA('inputs.xlsx', 'Constants', '25', 'C40')

Units: Dmnl

Share of natural gas for electricity in relation to the total
gas+coal.

Hist share liquids Elec:INTERPOLATE::=
GET XLS DATA('inputs.xlsx', 'Constants', '25', 'C39')

Units: Dmnl

Share of oil for electricity (Data extracted from database World
Bank: "Electricity production from oil sources (% of total) " /
"Electricity production from oil, gas and coal sources (% of
total)").

Historic efficiency gas for electricity(
GET XLS LOOKUPS('inputs.xlsx', 'Constants', '25', 'C70'))

Units: percent

Historical evolution of efficiency of natural gas power centrals
1990-2013 (IEA Balances).

FE nuclear Elec generation TWh[scenarios]=
extraction uranium EJ[scenarios]*efficiency uranium for electricity/EJ per TWh

Units: TWh/Year

Final energy electricity generation from uranium (TWh).

improvement efficiency gas for electricity=
IF THEN ELSE(Time<2013, (Historic efficiency gas for electricity(Time+1)-Historic efficiency gas for electricity (Time))*percent to share, efficiency gas for electricity*remaining efficiency improv gas for electricity *Efficiency improv gas for electricity)

Units: Dmnl

Annual efficiency improvement of the gas power centrals.

initial efficiency gas for electricity=
0.36399

Units: Dmnl

(IEA Balances).

Max efficiency gas power plants=
GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C48')

Units: Dnml

Assumed maximum efficiency level for gas power centrals.

PE demand coal for Elec EJ[scenarios]=

(FE demand coal for Elec TWh[scenarios]/efficiency coal for electricity)*EJ per TWh

Units: EJ/Year

Primary energy demand of coal (EJ) for electricity consumption

(including generation losses).

PE demand gas for Elec EJ[scenarios]=

(FE demand gas for Elec TWh[scenarios]/efficiency gas for electricity)*EJ per TWh

Units: EJ/Year

Primary energy demand of natural gas (EJ) for electricity

consumption (including generation losses).

PE demand liquids for Elec EJ[scenarios]=

(FE demand liquids for Elec TWh[scenarios]/efficiency liquids for electricity

)*EJ per TWh

Units: EJ/Year

Primary energy demand of oil (EJ) for electric generation

(including generation losses).

PE losses BioW for Elec EJ[scenarios]=

PE BioW for Elec generation EJ[scenarios]*(1-efficiency conversion bioE residues to Elec

)

Units: EJ/Year

(Primary energy) losses due to the production of electricity

from BioW.

PE losses uranium for Elec EJ[scenarios]=

extraction uranium EJ[scenarios]*(1-efficiency uranium for electricity)

Units: EJ/Year

(Primary) Energy losses in the generation of electricity in

nuclear power centrals.

percent to share=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C12')

Units: Dmnl

Conversion of percent to share.

remaining efficiency improv gas for electricity=

(Max efficiency gas power plants-efficiency gas for electricity)/Max efficiency gas power plants

Units: Dmnl

Remaining efficiency improvement for gas power centrals.

share coal for Elec[scenarios]=

1-"share gas/(coal+gas) for Elec"[scenarios]

Units: Dmnl

Coal is assumed to cover the rest of the electricity demand

after RES, nuclear, oil and gas.

"share gas/(coal+gas) for Elec"[scenarios]=

IF THEN ELSE(Time<2014, "Hist share gas/(coal+gas) Elec", "future share gas/(coal+gas) for Elec"

)

Units: Dmnl

Share of natural gas for electricity in relation to the total

gas+coal.

share liquids for Elec[scenarios]=

IF THEN ELSE(Time>2011, MAX(-0.0029251*Time dmnl[scenarios](Time)+5.91871,

0),Hist share liquids Elec)

Units: Dmnl

Oil share of electricity demand. Since this share has been

falling globally since the first oil shock, and given the

difficulties to substitute oil in other sectors (e.g.

Transportation) and that there are many more resources that can

supply electricity, we assume an exogenous linear decreasing

trend for the oil share of electricity demand to reach 0% around

2025. See Technical Report.

Time dmnl[scenarios](

[(1990,1990)-(2100,2100)],(1990,1990),(1991,1991),(1992,1992),(1993,1993),

(1994,1994),(1995,1995),(1996,1996),(1997,1997),(1998,1998),(1999,1999),(2000

,2000),(2001,2001),(2002,2002),(2003,2003),(2004,2004),(2005,2005),(2006,2006

),(2007,2007),(2008,2008),(2009,2009),(2010,2010),(2011,2011),(2012,2012),(
2013,2013),(2014,2014),(2015,2015),(2016,2016),(2017,2017),(2018,2018),(2019
,2019),(2020,2020),(2021,2021),(2022,2022),(2023,2023),(2024,2024),(2025,2025
),(2026,2026),(2027,2027),(2028,2028),(2029,2029),(2030,2030),(2031,2031),(
2032,2032),(2033,2033),(2034,2034),(2035,2035),(2036,2036),(2037,2037),(2038
,2038),(2039,2039),(2040,2040),(2041,2041),(2042,2042),(2043,2043),(2044,2044
),(2045,2045),(2046,2046),(2047,2047),(2048,2048),(2049,2049),(2050,2050),(
2051,2051),(2052,2052),(2053,2053),(2054,2054),(2055,2055),(2056,2056),(2057
,2057),(2058,2058),(2059,2059),(2060,2060),(2061,2061),(2062,2062),(2063,2063
),(2064,2064),(2065,2065),(2066,2066),(2067,2067),(2068,2068),(2069,2069),(
2070,2070),(2071,2071),(2072,2072),(2073,2073),(2074,2074),(2075,2075),(2076
,2076),(2077,2077),(2078,2078),(2079,2079),(2080,2080),(2081,2081),(2082,2082
),(2083,2083),(2084,2084),(2085,2085),(2086,2086),(2087,2087),(2088,2088),(
2089,2089),(2090,2090),(2091,2091),(2092,2092),(2093,2093),(2094,2094),(2095
,2095),(2096,2096),(2097,2097),(2098,2098),(2099,2099),(2100,2100))

Units: Dmnl

Vector that assigns for every year the number of that same year.

Total FE Elec demand TWh[scenarios]=

(FE demand Elec consum TWh[scenarios]+increase Elec demand for Transp TWh[
scenarios])*(1+share elec distribution losses)

Units: TWh/Year

Total final energy electricity demand (TWh). It includes new
electric uses (e.g. EV & HEV) and electrical distribution losses.

Total gen losses demand for Elec EJ[scenarios]=

PE demand gas for Elec EJ[scenarios]*(1-efficiency gas for electricity)+PE demand coal for Elec EJ
[scenarios]*(1-efficiency coal for electricity)+PE demand liquids for Elec EJ
[scenarios]*(1-efficiency liquids for electricity)+PE losses uranium for Elec EJ
[scenarios]+PE losses BioW for Elec EJ[scenarios]

Units: EJ/Year

Total generation losses associated to electricity demand.

5. ELEC – Demand of electricity from nuclear

abundance uranium[scenarios]=

IF THEN ELSE(PE demand uranium EJ[scenarios]=0, 1, IF THEN ELSE(extraction uranium EJ
[scenarios]>PE demand uranium EJ[scenarios

], 1, 1-((PE demand uranium EJ[scenarios]-extraction uranium EJ[scenarios
])/PE demand uranium EJ[scenarios])))
Units: Dmnl
The parameter abundance varies between (1;0). Abundance=1 while the supply covers the demand; the closest to 0 indicates a higher divergence between supply and demand.

Cp baseload reduction[scenarios]=
MIN(1,-0.6209*(Share variable vs base load Elec generation delayed 1yr[scenarios
])^2 - 0.3998*(Share variable vs base load Elec generation delayed 1yr[scenarios
]) + 1.0222)
Units: Dmnl
Reduction of the capacity factor of the baseload plants as a function of the penetration of variables RES in the electricity generation.

Cp nuclear[scenarios]=
Cp nuclear initial*Cp baseload reduction[scenarios]
Units: **undefined**
Capacity factor of nuclear power centrals.

Cp nuclear initial=
GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'F15')
Units: Dmnl
Capacity factor of nuclear taking historic data as reference: in 2011, there were 374 GW of nuclear capacity operating that generated 2,507 TWh.

Demand Elec NRE without liquids TWh[scenarios]=
MAX(Demand Elec NRE TWh[scenarios]-FE demand liquids for Elec TWh[scenarios
], 0)
Units: TWh/Year
Among the NRE, we assign priority to generation of oil from electricity since it is an exogenous assumption for all scenarios.

demand Nuclear TWh[scenarios]=

MIN(Nuclear capacity demand GW[scenarios]*Cp nuclear[scenarios]/(TWe per TWh *1000), Demand Elec NRE without liquids TWh[scenarios])

Units: TWh/Year

Demand electricity from nuclear (TWh). We introduce a minimum function to assure that no more nuclear than electricity required (after the RES and oil contribution) is produced.

effects shortage uranium[scenarios]=

IF THEN ELSE(abundance uranium[scenarios]>0.8, ((abundance uranium[scenarios]-0.8)*5)^2, 0)

Units: Dmnl

The eventual scarcity of coal would likely constrain the development of CTL. The proposed relationship avoids an abrupt limitation by introducing a range (1;0.8) in the gas abundance that constrains the development of CTL.

efficiency uranium for electricity=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C41')

Units: Dmnl

Efficiency of uranium in nuclear power centrals. [IEA Balances].

EJ per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C5')

Units: EJ/TWh

Unit conversion (3.6 EJ=1000 TWh)

Elec gen nuclear capacity available TWh[scenarios]=

Nuclear capacity GW[scenarios]*Cp nuclear[scenarios]/(TWe per TWh*1000)

Units: TWh/Year

Electricity generation compatible with the existing infraestructure.

Historic nuclear generation TWh(

GET XLS LOOKUPS('inputs.xlsx', 'Constants', '25', 'C69'))

Units: TWh/Year

Historic data of annual production from nuclear energy in TWh.

historic nuclear TWe[scenarios]=

IF THEN ELSE(Time<2011, (Historic nuclear generation TWh(Time+1)-Historic nuclear generation TWh (Time))*TWe per TWh, 0)

Units: TWe/Year

Historic data of annual production from nuclear energy in TWe.

Historic nuclear generation(Time)/8760

initial nuclear capacity GW=

initial Nuclear TWh*TWe per TWh*1000/Cp nuclear initial

Units: GW

Installed nuclear plants capacity (GW) in 1990.

initial Nuclear TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C69')

Units: TWh/Year

TWh generated by nuclear power plants in 1990.

invest cost nuclear:=

GET XLS DATA('inputs.xlsx', 'Parameters', '6', 'G15')

Units: Tdollars/TWe

Investment cost of nuclear power considering that future

reactors would require the same investment as the recent Hinkley

Point C nuclear power station in UK of 8,000 US$/kW.

invest nuclear Tdolar[scenarios]=

IF THEN ELSE(new nuclear capacity GW[scenarios]<0,0,(new nuclear capacity GW [scenarios]+replacement nuclear[scenarios])*invest cost nuclear/1000)

Units: Tdollars/Year

life time nuclear=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C15')

Units: Year

Lifetime of nuclear.

new nuclear capacity demand[scenarios]=

IF THEN ELSE(Time<2012, historic nuclear TWe[scenarios]*1000,

IF THEN ELSE(Selection of nuclear scenario[scenarios]=1,Nuclear capacity demand GW [scenarios]*P nuclear elec gen[scenarios

],

IF THEN ELSE(Selection of nuclear scenario[scenarios]=2,P nuclear elec gen

[scenarios]*1000,

IF THEN ELSE(Selection of nuclear scenario[scenarios]=3,P nuclear elec gen

[scenarios]*1000,

IF THEN ELSE(Selection of nuclear scenario[scenarios]=4,Nuclear capacity demand GW

[scenarios]*P nuclear elec gen[scenarios

],0)

))))/Cp nuclear[scenarios]

Units: GW/Year

New demand of new nuclear depending on the scenario chosen.

new nuclear capacity GW[scenarios]=

IF THEN ELSE(Time<2012, historic nuclear TWe[scenarios]*1000,

IF THEN ELSE(Selection of nuclear scenario[scenarios]=1,Nuclear capacity GW

[scenarios]*P nuclear elec gen[scenarios],

IF THEN ELSE(Selection of nuclear scenario[scenarios]=2,P nuclear elec gen

[scenarios]*1000,

IF THEN ELSE(Selection of nuclear scenario[scenarios]=3,P nuclear elec gen

[scenarios]*1000,

IF THEN ELSE(Selection of nuclear scenario[scenarios]=4,Nuclear capacity GW

[scenarios]*P nuclear elec gen[scenarios],0)

))))*effects shortage uranium[scenarios]/Cp nuclear[scenarios]

Units: GW/Year

New annual capacity installed depending on the scenario selected

and the uranium availability. IF THEN ELSE(Time<2012, historic nuclear TWe[scenarios]*1000, IF THEN ELSE(abundance uranium[scenarios]<1,0, IF THEN ELSE(Selection of nuclear scenario[scenarios]=1,Nuclear capacity GW[scenarios]*P nuclear elec gen[scenarios], IF THEN ELSE(Selection of nuclear scenario[scenarios]=2,P nuclear elec gen[scenarios]*1000, IF THEN ELSE(Selection of nuclear scenario[scenarios]=3,P nuclear elec gen[scenarios]*1000, IF THEN ELSE(Selection of nuclear scenario[scenarios]=4,Nuclear capacity GW[scenarios]*P nuclear elec gen[scenarios],0))))))/Cp nuclear[scenarios]

Nuclear capacity demand GW[scenarios]= INTEG (

new nuclear capacity demand[scenarios]+replacement nuclear demand[scenarios

]-wear nuclear demand[scenarios],

initial nuclear capacity GW)

Units: GW

Annual nuclear capacity demand depending on the scenario chosen.

Nuclear capacity GW[scenarios]= INTEG (

new nuclear capacity GW[scenarios]+replacement nuclear[scenarios]-wear nuclear

[scenarios],

initial nuclear capacity GW)

Units: GW

Nuclear capacity available (GW). It is assumed that when the

uranium starts to deplete (i.e. "abundance uranium"<1), no more

capacity is installed neither replaced.

P nuclear elec gen[scenarios]=

IF THEN ELSE(Selection of nuclear scenario[scenarios]=1, 0,

IF THEN ELSE(Selection of nuclear scenario[scenarios]=2,-scen 2N TWe[scenarios

],

IF THEN ELSE(Selection of nuclear scenario[scenarios]=3,-scen 3N TWe[scenarios

],

IF THEN ELSE(Selection of nuclear scenario[scenarios]=4, P nuclear scen 4N

[scenarios],0))))

Units: **undefined**

Nuclear evolution depending on the scenario selected in

Data.xlsx.

P nuclear scen 4N[scenarios]=

IF THEN ELSE(Time<start year nuclear growth scen4[scenarios], 0 , P nuclear scen4

[scenarios])

Units: 1/Year

Annual growth of nuclear power capacity. Scenario 4- Growth of

nuclear capacity at "P nuclear scen 4N" rate from the year 2015.

P nuclear scen4[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'D22')

P nuclear scen4[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'D22')

P nuclear scen4[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'D22')

P nuclear scen4[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'D22')

P nuclear scen4[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'D22')

P nuclear scen4[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'D22')

Units: 1/Year

Annual growth of new nuclear power plants (scenario 4 of nuclear evolution) from the year "start year nuclear growth scen4".

PE demand uranium EJ[scenarios]=

demand Nuclear TWh[scenarios]*EJ per TWh/efficiency uranium for electricity

Units: **undefined**

Primary energy demand of uranium for nuclear power generation.

replacement nuclear[scenarios]=

IF THEN ELSE(Selection of nuclear scenario[scenarios]=1,wear nuclear[scenarios
]*replacement rate nuclear,

IF THEN ELSE(Selection of nuclear scenario[scenarios]=2,0,

IF THEN ELSE(Selection of nuclear scenario[scenarios]=3,0,

IF THEN ELSE(Selection of nuclear scenario[scenarios]=4,wear nuclear[scenarios
]*replacement rate nuclear,0))

))

Units: GW/Year

If replacement rate=1, we asume that all the power that reaches the end of its lifetime is replaced. IF THEN ELSE(Selection of nuclear scenario[scenarios]=1,wear nuclear[scenarios]*replacement rate nuclear[scenarios], IF THEN ELSE(Selection of nuclear scenario[scenarios]=2,0, IF THEN ELSE(Selection of nuclear scenario[scenarios]=3,0, IF THEN ELSE(Selection of nuclear scenario[scenarios]=4,wear nuclear[scenarios]*replacement rate nuclear[scenarios],0))))*effects shortage uranium[scenarios] replacement nuclear demand[scenarios]=

IF THEN ELSE(Selection of nuclear scenario[scenarios]=1,wear nuclear demand [scenarios]*replacement rate nuclear,

IF THEN ELSE(Selection of nuclear scenario[scenarios]=2,0,

IF THEN ELSE(Selection of nuclear scenario[scenarios]=3,0,

IF THEN ELSE(Selection of nuclear scenario[scenarios]=4,wear nuclear demand [scenarios]*replacement rate nuclear,0))))

Units: GW

If replacement rate=1, we asume that all the capacity that reaches the end of its lifetime is replaced.

replacement rate nuclear=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'D15')

Units: Dmnl

If =1, we asume that all the power that reaches the end of its lifetime is replaced.

scen 2N GW:INTERPOLATE::=

GET XLS DATA('inputs.xlsx', 'Parameters', '17' , 'B18')

Units: GW/Year

Scenario 2 of nuclear evolution.

scen 2N TWe[scenarios]=

scen 2N GW*Cp nuclear[scenarios]/1000

Units: TWe/Year

Annual growth of nuclear power electricity generation. Scenario 2- Lifetime of the existing reactors = 40 years (including the planned new constructions, but no new constructions thereafter), progressive shut-down of the reactors in Germany.

scen 3N GW:INTERPOLATE::=

GET XLS DATA('inputs.xlsx', 'Parameters', '17' , 'B19')

Units: GW/Year

Scenario 3 of nuclear evolution.

scen 3N TWe[scenarios]=

scen 3N GW*Cp nuclear[scenarios]/1000

Units: TWe/Year

Annual growth of nuclear power electricity generation. Scenario 3- PLEX (Plant Life Extension): same than scenario 2 but with a lifetime of 60 years.

Selection of nuclear scenario[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'G19')

Selection of nuclear scenario[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'G19')

Selection of nuclear scenario[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'G19')

Selection of nuclear scenario[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'G19')

Selection of nuclear scenario[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'G19')

Selection of nuclear scenario[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'G19')

Units: Dmnl

Selection of the nuclear scenario in "inputs.xlsx": 1- Constant power capacity at current levels (value of 2006-2007) 2- Lifetime of the existing reactors = 40 years (including the planned new constructions, but no new constructions thereafter), progressive shut-down of the reactors in Germany. 3- PLEX (Plant Life Extension): same than scenario 2 but with a lifetime of 60 years. 4- Growth of nuclear power at "P nuclear scen 4N" rate from the year 2015.

start year nuclear growth scen4[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'F22')

start year nuclear growth scen4[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'F22')

start year nuclear growth scen4[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'F22')

start year nuclear growth scen4[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'F22')

start year nuclear growth scen4[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'F22')

start year nuclear growth scen4[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'F22')

Units: Year

Start year of growth of nuclear power plants (Nuclear scenario

4).

TWe per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C7')

Units: TWe/(TWh/Year)

Unit conversion (1 TWe=8760 TWh per year)

wear nuclear[scenarios]=

IF THEN ELSE(Selection of nuclear scenario[scenarios]=1,Nuclear capacity GW

[scenarios]/life time nuclear,

IF THEN ELSE(Selection of nuclear scenario[scenarios]=2,0,

IF THEN ELSE(Selection of nuclear scenario[scenarios]=3,0,

IF THEN ELSE(Selection of nuclear scenario[scenarios]=4,Nuclear capacity GW

[scenarios]/life time nuclear,0))))

Units: GW/Year

Decommission of the capacity that reaches the end of its lifetime.

wear nuclear demand[scenarios]=

IF THEN ELSE(Selection of nuclear scenario[scenarios]=1,Nuclear capacity demand GW

[scenarios]/life time nuclear,

IF THEN ELSE(Selection of nuclear scenario[scenarios]=2,0,

IF THEN ELSE(Selection of nuclear scenario[scenarios]=3,0,

IF THEN ELSE(Selection of nuclear scenario[scenarios]=4,Nuclear capacity demand GW

[scenarios]/life time nuclear,0))))

Units: GW

Decommission of the capacity that reaches the end of its lifetime.

6. ELEC – Electricity related losses

Elec gen related losses EJ[scenarios]=

PE losses coal for Elec EJ[scenarios]+PE losses conv gas for Elec EJ[scenarios

]+PE losses uranium for Elec EJ[scenarios

]+PE losses uncon gas for Elec EJ[scenarios]+PE losses oil for Elec EJ[scenarios

]+PE losses BioW for Elec EJ[scenarios]

Units: EJ/Year

Electricity generation losses (EJ).

Electrical distribution losses EJ[scenarios]=

Electrical distribution losses TWh[scenarios]*EJ per TWh

Units: EJ/Year

Electical distribution losses (EJ)

GDP[scenarios]=

GDPcap[scenarios]*Population[scenarios]/dollars to Tdollars

Units: Tdollars/Year

Global Domestic Product.

Gen losses vs PE for elec[scenarios]=

Elec gen related losses EJ[scenarios]/Total PE for electricity consumption EJ

[scenarios]

Units: Dmnl

Generation losses as a share of the total PE for electricity.

MToe per EJ=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C6')

Units: MToe/EJ

Unit conversion (1000 Mtoe=41.868 EJ)

PE losses BioW for Elec EJ[scenarios]=

PE BioW for Elec generation EJ[scenarios]*(1-efficiency conversion bioE residues to Elec

)

Units: EJ/Year

(Primary energy) losses due to the production of electricity

from BioW.

PE losses coal for Elec EJ[scenarios]=

extraction coal without CTL EJ[scenarios]*"share coal/sector for Elec"[scenarios

]*(1-efficiency coal for electricity)

Units: EJ/Year

(Primary) Energy losses in the generation of electricity in coal power centrals.

PE losses conv gas for Elec EJ[scenarios]=

extraction conv gas without GTL EJ[scenarios]*"share gas/sector for Elec"[

scenarios]*(1-efficiency gas for electricity)

Units: EJ/Year

(Primary) Energy losses in the generation of electricity in gas

power centrals.

PE losses oil for Elec EJ[scenarios]=

Liquids extraction EJ[scenarios]*"share liquids/sector for Elec"[scenarios

]*(1-efficiency liquids for electricity)

Units: EJ/Year

Primary energy losses related with oil for electricity

generation.

PE losses uncon gas for Elec EJ[scenarios]=

extraction unconv gas EJ[scenarios]*"share gas/sector for Elec"[scenarios]

*(1-efficiency gas for electricity)

Units: EJ/Year

(Primary) Energy losses in the generation of electricity in gas

power centrals.

PE losses uranium for Elec EJ[scenarios]=

extraction uranium EJ[scenarios]*(1-efficiency uranium for electricity)

Units: EJ/Year

(Primary) Energy losses in the generation of electricity in

nuclear power centrals.

real PED intensity of Electricity[scenarios]=

(Total FE Elec demand EJ[scenarios]+Elec gen related losses EJ[scenarios])

/GDP[scenarios]

Units: EJ/Tdollars

Primary energy demand intensity of the electricity sector. Note

that the parameter "'a' I-ELEC projection" refers to final

energy while here we refer to primary energy. The "real PED

intensity of electricity" may thus decrease with the penetration of RES in the electricity generation (see "share RES vs NRE electricity generation").

Total electrical losses EJ[scenarios]=

Elec gen related losses EJ[scenarios]+Electrical distribution losses EJ[scenarios
]

Units: EJ/Year

Total losses from electricity generation (generation + distribution).

Total FE Elec demand EJ[scenarios]=

Total FE Elec demand TWh[scenarios]*EJ per TWh

Units: EJ/Year

Electricity demand generation (final energy, includes distribution losses).

Total PE for electricity consumption EJ[scenarios]=

Total FE Elec demand EJ[scenarios]+Elec gen related losses EJ[scenarios]

Units: EJ/Year

Total primary energy for electricity consumption (EJ).

7. ELEC RES – Hydro

abundance electricity RES[scenarios]=

SQRT(ABS((Total FE Elec demand TWh[scenarios]-FE Elec generation from RES TWh [scenarios])/Total FE Elec demand TWh[scenarios]))

Units: **undefined**

adapt growth hydro[scenarios]=

IF THEN ELSE(Time<2014, past hydro, IF THEN ELSE(Time<2019, past hydro+(P hydro [scenarios]-past hydro)*(Time dmnl[scenarios](Time)-2014)/5, P hydro[scenarios
]))

Units: 1/Year

Modeling of a soft transition from current historic annual growth to reach the policy-objective 5 years later.

capacity hydro[scenarios]=

hydro TWe[scenarios]/Cp hydro[scenarios]

Units: TW

Installed capacity.

check electricity[scenarios]=

(Total FE Elec demand TWh[scenarios]-Total FE Elec generation TWh[scenarios
])/Total FE Elec generation TWh[scenarios]

Units: Dmnl

If=1: demand=supply. If>0: demand>supply. If<0: demand<supply.
Variable to avoid energy oversupply caused by exogenously driven
policies.

"constrain electricity exogenous growth?"[scenarios]=

IF THEN ELSE(check electricity[scenarios]>-0.01 ,1 ,check electricity[scenarios
])

Units: Dmnl

If negative, there is oversupply of electricity. This variable
is used to constrain the exogenous growth of exogenously-driven
policies.

Cp baseload reduction[scenarios]=

MIN(1,-0.6209*(Share variable vs base load Elec generation delayed 1yr[scenarios
])^2 - 0.3998*(Share variable vs base load Elec generation delayed 1yr[scenarios
]) + 1.0222)

Units: Dmnl

Reduction of the capacity factor of the baseload plants as a
function of the penetration of variables RES in the electricity
generation.

Cp hydro[scenarios]=

Cp hydro initial*Cp baseload reduction[scenarios]

Units: **undefined**

Capacity factor of hydroelectric power plants.

Cp hydro initial:INTERPOLATE::=

GET XLS DATA('inputs.xlsx', 'Parameters', '6', 'G13')

Units: Dmnl

Capacity factor in the period 1990-2010. Source: EIA (2009).

EJ per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C5')

Units: EJ/TWh

Unit conversion (3.6 EJ=1000 TWh)

FE Elec generation from hydro TWh[scenarios]=

hydro TWe[scenarios]/TWe per TWh

Units: TWh/Year

Annual electricity generation.

FE Elec generation from RES TWh[scenarios]=

FE Elec generation from BioW TWh[scenarios]+FE Elec generation from geot TWh [scenarios]+FE Elec generation from hydro TWh[scenarios]+FE Elec generation from solar TWh [scenarios]+FE Elec generation from onshore wind TWh[scenarios]+FE Elec generation from offshore wind TWh [scenarios]+FE Elec generation from oceanic TWh[scenarios]

Units: TWh/Year

Final energy electricity generation from RES (TWh).

gCO2e per kWh hydro=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'E13')

Units: gCO2e/kWh

CO2eq emissions. Source Arvesen et al (2011). 17-22 gCO2e/kWh

hydro evol[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C32')

hydro evol[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C32')

hydro evol[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C32')

hydro evol[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C32')

hydro evol[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C32')

hydro evol[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C32')

Units: Dmnl

Annual growth in energy output as a function of past trends.

GtCO2e hydro[scenarios]=

FE Elec generation from hydro TWh[scenarios]*gCO2e per kWh hydro*GTCO2e per gCO2e

*kWh per TWh

Units: GTCO2e/Year

Annual CO2e emissions.

GTCO2e per gCO2e=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C8')

Units: GTCO2e/gCO2e

Conversion between GTCO2 and gCO2 (1 GT = 1e15 g).

Historic hydro generation(

GET XLS LOOKUPS('inputs.xlsx', 'Constants', '25', 'C63'))

Units: TWh/Year

Annual historic electricity generation from hydroelectricity

(1990-2015). Ref: BP 2016.

hydro TWe[scenarios]= INTEG (

new hydro TWe[scenarios]+replacement hydro[scenarios]-wear hydro[scenarios

],

initial hydro TWe)

Units: TWe

Annual electricity generation.

initial hydro TWe=

initial hydro TWh*TWe per TWh

Units: TWe

Electricity generated by hydroelectric power plants in 1990.

initial hydro TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C63')

Units: TWh

TWh generated by hydro in 1990 (BP, 2016).

Invest cost hydro:INTERPOLATE::=

GET XLS DATA('inputs.xlsx', 'Parameters', '6', 'G14')

Units: Tdollars/TWe

Investments costs per TWe (without operation & maintenance) from
the scenario "Energy [R]evolution 2010" (Teske et al., 2011).

invest hydro Tdolar[scenarios]=

(new hydro TWe[scenarios]+replacement hydro[scenarios])*(Invest cost hydro /Cp hydro[scenarios])

Units: Tdollars/Year

Investment costs.

kWh per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C9')

Units: kWh/TWh

Conversion between kWh and TWh (1 TWh=1e9 kWh).

life time hydro=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C13')

Units: Year

Lifetime power plants.

max hydro TWe[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C24')

max hydro TWe[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C24')

max hydro TWe[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C24')

max hydro TWe[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C24')

max hydro TWe[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C24')

max hydro TWe[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C24')

Units: TWe

Techno-ecological potential of hydro (1 TWe = 8760 TWh in one
year).

MToe per EJ=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C6')

Units: MToe/EJ

Unit conversion (1000 Mtoe=41.868 EJ)

new hydro TWe[scenarios]=

IF THEN ELSE(Time<2014, (Historic hydro generation(Time+1)-Historic hydro generation (Time))*TWe per TWh,

IF THEN ELSE(check electricity[scenarios]<-0.01, "constrain electricity exogenous growth?" [scenarios]*hydro TWe[scenarios

],adapt growth hydro[scenarios]*hydro TWe[scenarios]*Remaining potential hydro [scenarios]))

Units: TWe

New annual hydro electric power (TWe) installed. IF THEN ELSE(Time<2014, (Historic hydro generation(Time+1)-Historic hydro generation(Time))*TWe per TWh, IF THEN ELSE(check electricity[scenarios]<-0.01, "constrain electricity exogenous growth?"[scenarios]*hydro TWe[scenarios],adapt growth hydro[scenarios]*hydro TWe[scenarios]*Remaining potential hydro[scenarios])) IF THEN ELSE(Time<2014, (Historic hydro generation(Time+1)-Historic hydro generation(Time))*TWe per TWh, IF THEN ELSE(Total FE Elec demand TWh[scenarios]>FE Elec generation from RES TWh[scenarios], adapt growth hydro[scenarios]*hydro TWe[scenarios]*Remaining potential hydro[scenarios],"constrain electricity exogenous growth?"[scenarios]*hydro TWe[scenarios]))

P hydro[scenarios]=

past hydro*hydro evol[scenarios]*abundance electricity RES[scenarios]

Units: 1/Year

Annual growth in energy output demand depending on the policy of the scenario.

past hydro=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C87')

Units: 1/Year

Current growth patterns (1990-2015).

PE hydro for Elec generation EJ[scenarios]=

FE Elec generation from hydro TWh[scenarios]*EJ per TWh

Units: EJ/Year

Annual primary energy to generate electricity (Direct Equivalent Method).

power density hydro=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'B13')

Units: TWe/MHa

Power density: 4 We/m2 (de Castro et al., 2013b; Smil, 2015)

Remaining potential hydro[scenarios]=

(max hydro TWe[scenarios]-hydro TWe[scenarios])/max hydro TWe[scenarios]

Units: Dmnl

Remaining potential available as a fraction of unity.

replacement hydro[scenarios]=

wear hydro[scenarios]*replacement rate hydro

Units: TWe

If replacement rate=1, we asume that all the power that reaches the end of its lifetime is replaced.

replacement rate hydro=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'D13')

Units: Dmnl

If =1, we asume that all the power that reaches the end of its lifetime is replaced.

surface hydro[scenarios]=

hydro TWe[scenarios]/power density hydro

Units: MHa

Surface required to produce "hydro TWe".

Time 95pc TS potential hydro[scenarios]=

IF THEN ELSE(Remaining potential hydro[scenarios]>0.05, 0, Time)

Units: Year

Time when the remaining resource availability falls bellow 5% of
the techno-ecological potential, i.e. when the 95% of the
techno-ecological potential is reached.

Time dmnl[scenarios](
[(1990,1990)-(2100,2100)],(1990,1990),(1991,1991),(1992,1992),(1993,1993),(1994,1994),(1995,1995),(1996,1996),(1997,1997),(1998,1998),(1999,1999),(2000,2000),(2001,2001),(2002,2002),(2003,2003),(2004,2004),(2005,2005),(2006,2006),(2007,2007),(2008,2008),(2009,2009),(2010,2010),(2011,2011),(2012,2012),(2013,2013),(2014,2014),(2015,2015),(2016,2016),(2017,2017),(2018,2018),(2019,2019),(2020,2020),(2021,2021),(2022,2022),(2023,2023),(2024,2024),(2025,2025),(2026,2026),(2027,2027),(2028,2028),(2029,2029),(2030,2030),(2031,2031),(2032,2032),(2033,2033),(2034,2034),(2035,2035),(2036,2036),(2037,2037),(2038,2038),(2039,2039),(2040,2040),(2041,2041),(2042,2042),(2043,2043),(2044,2044),(2045,2045),(2046,2046),(2047,2047),(2048,2048),(2049,2049),(2050,2050),(2051,2051),(2052,2052),(2053,2053),(2054,2054),(2055,2055),(2056,2056),(2057,2057),(2058,2058),(2059,2059),(2060,2060),(2061,2061),(2062,2062),(2063,2063),(2064,2064),(2065,2065),(2066,2066),(2067,2067),(2068,2068),(2069,2069),(2070,2070),(2071,2071),(2072,2072),(2073,2073),(2074,2074),(2075,2075),(2076,2076),(2077,2077),(2078,2078),(2079,2079),(2080,2080),(2081,2081),(2082,2082),(2083,2083),(2084,2084),(2085,2085),(2086,2086),(2087,2087),(2088,2088),(2089,2089),(2090,2090),(2091,2091),(2092,2092),(2093,2093),(2094,2094),(2095,2095),(2096,2096),(2097,2097),(2098,2098),(2099,2099),(2100,2100))

Units: Dmnl

Vector that assigns for every year the number of that same year.

Total FE Elec demand TWh[scenarios]=
(FE demand Elec consum TWh[scenarios]+increase Elec demand for Transp TWh[scenarios])*(1+share elec distribution losses)

Units: TWh/Year

Total final energy electricity demand (TWh). It includes new
electric uses (e.g. EV & HEV) and electrical distribution losses.

TWe per TWh=
GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C7')

Units: TWe/(TWh/Year)

Unit conversion (1 TWe=8760 TWh per year) wear hydro[scenarios]=

hydro TWe[scenarios]/life time hydro

Units: TWe

Decommission of the capacity that reachs the end of its lifetime.

8. ELEC RES- Geothermal for elec

abundance electricity RES[scenarios]=

SQRT(ABS((Total FE Elec demand TWh[scenarios]-FE Elec generation from RES TWh [scenarios])/Total FE Elec demand TWh[scenarios]))

Units: **undefined**

adapt growth hydro[scenarios]=

IF THEN ELSE(Time<2014, past hydro, IF THEN ELSE(Time<2019, past hydro+(P hydro [scenarios]-past hydro)*(Time dmnl[scenarios](Time)-2014)/5, P hydro[scenarios]))

Units: 1/Year

Modeling of a soft transition from current historic annual growth to reach the policy-objective 5 years later.

capacity hydro[scenarios]=

hydro TWe[scenarios]/Cp hydro[scenarios]

Units: TW

Installed capacity.

check electricity[scenarios]=

(Total FE Elec demand TWh[scenarios]-Total FE Elec generation TWh[scenarios])/Total FE Elec generation TWh[scenarios]

Units: Dmnl

If=1: demand=supply. If>0: demand>supply. If<0: demand<supply. Variable to avoid energy oversupply caused by exogenously driven policies.

"constrain electricity exogenous growth?"[scenarios]=

IF THEN ELSE(check electricity[scenarios]>-0.01 ,1 ,check electricity[scenarios])

Units: Dmnl

If negative, there is oversupply of electricity. This variable
is used to constrain the exogenous growth of exogenously-driven
policies.

Cp baseload reduction[scenarios]=
MIN(1,-0.6209*(Share variable vs base load Elec generation delayed 1yr[scenarios
])^2 - 0.3998*(Share variable vs base load Elec generation delayed 1yr[scenarios
]) + 1.0222)
Units: Dmnl
Reduction of the capacity factor of the baseload plants as a
function of the penetration of variables RES in the electricity
generation.

Cp hydro[scenarios]=
Cp hydro initial*Cp baseload reduction[scenarios]
Units: **undefined**
Capacity factor of hydroelectric power plants.

Cp hydro initial:INTERPOLATE::=
GET XLS DATA('inputs.xlsx', 'Parameters', '6', 'G13')
Units: Dmnl
Capacity factor in the period 1990-2010. Source: EIA (2009).

EJ per TWh=
GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C5')
Units: EJ/TWh
Unit conversion (3.6 EJ=1000 TWh)

FE Elec generation from hydro TWh[scenarios]=
hydro TWe[scenarios]/TWe per TWh
Units: TWh/Year
Annual electricity generation.

FE Elec generation from RES TWh[scenarios]=
FE Elec generation from BioW TWh[scenarios]+FE Elec generation from geot TWh
[scenarios]+FE Elec generation from hydro TWh[scenarios]+FE Elec generation from solar TWh
[scenarios]+FE Elec generation from onshore wind TWh[scenarios]+FE Elec generation from offshore wind TWh

[scenarios]+FE Elec generation from oceanic TWh[scenarios]

Units: TWh/Year

Final energy electricity generation from RES (TWh).

gCO2e per kWh hydro=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'E13')

Units: gCO2e/kWh

CO2eq emissions. Source Arvesen et al (2011). 17-22 gCO2e/kWh

hydro evol[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C32')

hydro evol[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C32')

hydro evol[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C32')

hydro evol[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C32')

hydro evol[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C32')

hydro evol[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C32')

Units: Dmnl

Annual growth in energy output as a function of past trends.

GtCO2e hydro[scenarios]=

FE Elec generation from hydro TWh[scenarios]*gCO2e per kWh hydro*GTCO2e per gCO2e

*kWh per TWh

Units: GTCO2e/Year

Annual CO2e emissions.

GTCO2e per gCO2e=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C8')

Units: GTCO2e/gCO2e

Conversion between GTCO2 and gCO2 (1 GT = 1e15 g).

Historic hydro generation(

GET XLS LOOKUPS('inputs.xlsx', 'Constants', '25', 'C63'))

Units: TWh/Year

Annual historic electricity generation from hydroelectricity

(1990-2015). Ref: BP 2016.

hydro TWe[scenarios]= INTEG (

new hydro TWe[scenarios]+replacement hydro[scenarios]-wear hydro[scenarios

],

initial hydro TWe)

Units: TWe

Annual electricity generation.

initial hydro TWe=

initial hydro TWh*TWe per TWh

Units: TWe

Electricity generated by hydroelectric power plants in 1990.

initial hydro TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C63')

Units: TWh

TWh generated by hydro in 1990 (BP, 2016).

Invest cost hydro:INTERPOLATE::=

GET XLS DATA('inputs.xlsx', 'Parameters', '6', 'G14')

Units: Tdollars/TWe

Investments costs per TWe (without operation & maintenance) from

the scenario "Energy [R]evolution 2010" (Teske et al., 2011).

invest hydro Tdolar[scenarios]=

(new hydro TWe[scenarios]+replacement hydro[scenarios])*(Invest cost hydro

/Cp hydro[scenarios])

Units: Tdollars/Year

Investment costs.

kWh per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C9')

Units: kWh/TWh

Conversion between kWh and TWh (1 TWh=1e9 kWh).

life time hydro=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C13')

Units: Year

Lifetime power plants.

max hydro TWe[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C24')

max hydro TWe[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C24')

max hydro TWe[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C24')

max hydro TWe[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C24')

max hydro TWe[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C24')

max hydro TWe[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C24')

Units: TWe

Techno-ecological potential of hydro (1 TWe = 8760 TWh in one year).

MToe per EJ=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C6')

Units: MToe/EJ

Unit conversion (1000 Mtoe=41.868 EJ)

new hydro TWe[scenarios]=

IF THEN ELSE(Time<2014, (Historic hydro generation(Time+1)-Historic hydro generation (Time))*TWe per TWh,

IF THEN ELSE(check electricity[scenarios]<-0.01, "constrain electricity exogenous growth?"[scenarios]*hydro TWe[scenarios

],adapt growth hydro[scenarios]*hydro TWe[scenarios]*Remaining potential hydro [scenarios]))

Units: TWe

New annual hydro electric power (TWe) installed. IF THEN

ELSE(Time<2014, (Historic hydro generation(Time+1)-Historic hydro generation(Time))*TWe per TWh, IF THEN ELSE(check electricity[scenarios]<-0.01, "constrain electricity exogenous growth?"[scenarios]*hydro TWe[scenarios],adapt growth hydro[scenarios]*hydro TWe[scenarios]*Remaining potential hydro[scenarios])) IF THEN ELSE(Time<2014, (Historic hydro generation(Time+1)-Historic hydro generation(Time))*TWe per TWh, IF THEN ELSE(Total FE Elec demand TWh[scenarios]>FE Elec generation from RES TWh[scenarios], adapt growth hydro[scenarios]*hydro TWe[scenarios]*Remaining potential hydro[scenarios],"constrain electricity exogenous growth?"[scenarios]*hydro TWe[scenarios]))

P hydro[scenarios]=

past hydro*hydro evol[scenarios]*abundance electricity RES[scenarios]

Units: 1/Year

Annual growth in energy output demand depending on the policy of the scenario.

past hydro=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C87')

Units: 1/Year

Current growth patterns (1990-2015).

PE hydro for Elec generation EJ[scenarios]=

FE Elec generation from hydro TWh[scenarios]*EJ per TWh

Units: EJ/Year

Annual primary energy to generate electricity (Direct Equivalent Method).

power density hydro=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'B13')

Units: TWe/MHa

Power density: 4 We/m2 (de Castro et al., 2013b; Smil, 2015)

Remaining potential hydro[scenarios]=

(max hydro TWe[scenarios]-hydro TWe[scenarios])/max hydro TWe[scenarios]

Units: Dmnl

Remaining potential available as a fraction of unity.

replacement hydro[scenarios]=

wear hydro[scenarios]*replacement rate hydro

Units: TWe

If replacement rate=1, we asume that all the power that reaches

the end of its lifetime is replaced.

replacement rate hydro=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'D13')

Units: Dmnl

If =1, we asume that all the power that reaches the end of its

lifetime is replaced.

surface hydro[scenarios]=

hydro TWe[scenarios]/power density hydro

Units: MHa

Surface required to produce "hydro TWe".

Time 95pc TS potential hydro[scenarios]=

IF THEN ELSE(Remaining potential hydro[scenarios]>0.05, 0, Time)

Units: Year

Time when the remaining resource availability falls bellow 5% of

the techno-ecological potential, i.e. when the 95% of the

techno-ecological potential is reached.

Time dmnl[scenarios](

[(1990,1990)-(2100,2100)],(1990,1990),(1991,1991),(1992,1992),(1993,1993),
(1994,1994),(1995,1995),(1996,1996),(1997,1997),(1998,1998),(1999,1999),(2000
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2013,2013),(2014,2014),(2015,2015),(2016,2016),(2017,2017),(2018,2018),(2019
,2019),(2020,2020),(2021,2021),(2022,2022),(2023,2023),(2024,2024),(2025,2025
),(2026,2026),(2027,2027),(2028,2028),(2029,2029),(2030,2030),(2031,2031),(
2032,2032),(2033,2033),(2034,2034),(2035,2035),(2036,2036),(2037,2037),(2038
,2038),(2039,2039),(2040,2040),(2041,2041),(2042,2042),(2043,2043),(2044,2044
),(2045,2045),(2046,2046),(2047,2047),(2048,2048),(2049,2049),(2050,2050),(

2051,2051),(2052,2052),(2053,2053),(2054,2054),(2055,2055),(2056,2056),(2057
,2057),(2058,2058),(2059,2059),(2060,2060),(2061,2061),(2062,2062),(2063,2063
),(2064,2064),(2065,2065),(2066,2066),(2067,2067),(2068,2068),(2069,2069),(
2070,2070),(2071,2071),(2072,2072),(2073,2073),(2074,2074),(2075,2075),(2076
,2076),(2077,2077),(2078,2078),(2079,2079),(2080,2080),(2081,2081),(2082,2082
),(2083,2083),(2084,2084),(2085,2085),(2086,2086),(2087,2087),(2088,2088),(
2089,2089),(2090,2090),(2091,2091),(2092,2092),(2093,2093),(2094,2094),(2095
,2095),(2096,2096),(2097,2097),(2098,2098),(2099,2099),(2100,2100))

Units: Dmnl

Vector that assigns for every year the number of that same year.

Total FE Elec demand TWh[scenarios]=

(FE demand Elec consum TWh[scenarios]+increase Elec demand for Transp TWh[
scenarios])*(1+share elec distribution losses)

Units: TWh/Year

Total final energy electricity demand (TWh). It includes new
electric uses (e.g. EV & HEV) and electrical distribution losses.

TWe per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C7')

Units: TWe/(TWh/Year)

Unit conversion (1 TWe=8760 TWh per year)

wear hydro[scenarios]=

hydro TWe[scenarios]/life time hydro

Units: TWe

Decommission of the capacity that reachs the end of its lifetime.

abundance electricity RES[scenarios]=

SQRT(ABS((Total FE Elec demand TWh[scenarios]-FE Elec generation from RES TWh
[scenarios])/Total FE Elec demand TWh[scenarios]))

Units: **undefined**

"adapt growth geot-elec"[scenarios]=

IF THEN ELSE(Time<2012, "past geot-elec", IF THEN ELSE(Time<2017, "past geot-elec"
+("P geot-elec"[scenarios]-"past geot-elec")*(Time dmnl[scenarios](Time)-2012
)/5, "P geot-elec"[scenarios]))

Units: 1/Year

Modeling of a soft transition from current historic annual

growth to reach the policy-objective 5 years later.

"capacity geot-elec"[scenarios]=

"geot-elec TWe"[scenarios]/"Cp geot-elec"[scenarios]

Units: TW

Installed capacity.

check electricity[scenarios]=

(Total FE Elec demand TWh[scenarios]-Total FE Elec generation TWh[scenarios

])/Total FE Elec generation TWh[scenarios]

Units: Dmnl

If=1: demand=supply. If>0: demand>supply. If<0: demand<supply.

Variable to avoid energy oversupply caused by exogenously driven

policies.

"constrain electricity exogenous growth?"[scenarios]=

IF THEN ELSE(check electricity[scenarios]>-0.01 ,1 ,check electricity[scenarios

])

Units: Dmnl

If negative, there is oversupply of electricity. This variable

is used to constrain the exogenous growth of exogenously-driven

policies.

Cp baseload reduction[scenarios]=

MIN(1,-0.6209*(Share variable vs base load Elec generation delayed 1yr[scenarios

])^2 - 0.3998*(Share variable vs base load Elec generation delayed 1yr[scenarios

]) + 1.0222)

Units: Dmnl

Reduction of the capacity factor of the baseload plants as a

function of the penetration of variables RES in the electricity

generation.

"Cp geot-elec initial"=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'F7')

Units: Dmnl

Current capacity factor of geothermal power plants. Source: EIA (2009).

"Cp geot-elec"[scenarios]=
"Cp geot-elec initial"*Cp baseload reduction[scenarios]
Units: **undefined**
Capacity factor of geothermal power plants.

Efficiency conversion geot PE to Elec=
GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C42')
Units: Dmnl
Efficiency of the transformation from geothermal (primary energy) to electricity.

EJ per TWh=
GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C5')
Units: EJ/TWh
Unit conversion (3.6 EJ=1000 TWh)

FE Elec generation from geot TWh[scenarios]=
"geot-elec TWe"[scenarios]/TWe per TWh
Units: TWh/Year
Annual electricity generation.

"gCO2e per KWh geot-elec"=
GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'E7')
Units: gCO2e/kWh
CO2eq emissions. Source Arvesen et al (2011). 15.1-55 gCO2e/KWh

"geot-elec evol"[BAU]=
GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C33')
"geot-elec evol"[SCEN1]=
GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C33')
"geot-elec evol"[SCEN2]=
GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C33')
"geot-elec evol"[SCEN3]=
GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C33')

"geot-elec evol"[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C33')

"geot-elec evol"[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C33')

Units: Dmnl

Annual growth in energy output as a function of past trends.

"geot-elec TWe"[scenarios]= INTEG (

"new geot-elec TWe"[scenarios]+"replacement geot-elec"[scenarios]-"wear geot-elec"
[scenarios],

"initial geot-elec TWe")

Units: TWe

Annual electricity generation.

Geothermal PE potential TWth[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C56')

Geothermal PE potential TWth[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C56')

Geothermal PE potential TWth[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C56')

Geothermal PE potential TWth[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C56')

Geothermal PE potential TWth[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C56')

Geothermal PE potential TWth[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C56')

Units: TWth

Geothermal primary energy potential.

"initial geot-elec TWe"=

"initial geot-elec TWh"*TWe per TWh

Units: TWe

Electricity generated by geothermal in 1990.

"initial geot-elec TWh"=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C57')

Units: TWh

36 TWh generated in 1990 (US EIA database).

"GtCO2e geot-elec"[scenarios]=

FE Elec generation from geot TWh[scenarios]*GTCO2e per gCO2e*"gCO2e per KWh geot-elec"

*kWh per TWh

Units: GTCO2e/Year

Annual CO2e emissions.

GTCO2e per gCO2e=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C8')

Units: GTCO2e/gCO2e

Conversion between GTCO2 and gCO2 (1 GT = 1e15 g).

"Historic geot-elec generation"(

GET XLS LOOKUPS('inputs.xlsx', 'Constants', '25', 'C57'))

Units: TWh/Year

Annual historic electricity generation from geothermal

technologies (1990-2013). Ref: US EIA.

"Invest cost geot-elec":INTERPOLATE::=

GET XLS DATA('inputs.xlsx', 'Parameters', '6', 'G7')

Units: Tdollars/TWe

Investments costs per TWe (without operation & maintenance) from

the scenario "Energy [R]evolution 2010" (Teske et al., 2011).

"invest geot-elec Tdolar"[scenarios]=

("new geot-elec TWe"[scenarios]+"replacement geot-elec"[scenarios])*("Invest cost geot-elec"

/"Cp geot-elec"[scenarios])

Units: Tdollars/Year

Investment costs.

kWh per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C9')

Units: kWh/TWh

Conversion between kWh and TWh (1 TWh=1e9 kWh).

"life time geot-elec"=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C7')

Units: Year

Lifetime power plants.

"max geot-elec TWe"[scenarios]=

Geothermal PE potential TWth[scenarios]*share geot for elec[scenarios]*Efficiency conversion geot PE to Elec

Units: TWe

Techno-ecological potential of electric geothermal (1 TWe = 8760 TWh in one year). We assume that the global potential of 0.2 TWe is shared at 50% for heat and electric purposes. See Technical Report.

"new geot-elec TWe"[scenarios]=

IF THEN ELSE(Time<2012, ("Historic geot-elec generation"(Time+1)-"Historic geot-elec generation"(Time))*TWe per TWh,

IF THEN ELSE(check electricity[scenarios]<-0.01, "constrain electricity exogenous growth?"[scenarios]*"geot-elec TWe"[scenarios],

"adapt growth geot-elec"[scenarios]*"geot-elec TWe"[scenarios]*"Remaining potential geot-elec"[scenarios]))

Units: TWe

New annual geot electric power installed (TWe).

"P geot-elec"[scenarios]=

"past geot-elec"*"geot-elec evol"[scenarios]*abundance electricity RES[scenarios
]

Units: 1/Year

Annual growth in energy output demand depending on the policy of the scenario.

"past geot-elec"=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C82')

Units: 1/Year

Current growth patterns (1990-2013).

PE geot for Elec generation EJ[scenarios]=

FE Elec generation from geot TWh[scenarios]*EJ per TWh

Units: EJ/Year

Annual primary energy to generate electricity (Direct Equivalent
Method).

"power density geot-elec"=
GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'B7')
Units: TWe/MHa
Power density: 50 We/m2 (de Castro et al., 2013b; Smil, 2015)

"Remaining potential geot-elec"[scenarios]=
("max geot-elec TWe"[scenarios]-"geot-elec TWe"[scenarios])/"max geot-elec TWe"
[scenarios]
Units: Dmnl
Remaining potential available as a fraction of unity.

"replacement geot-elec"[scenarios]=
"wear geot-elec"[scenarios]*"replacement rate geot-elec"
Units: TWe
If replacement rate=1, we asume that all the power that reaches
the end of its lifetime is replaced.

"replacement rate geot-elec"=
GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'D7')
Units: Dmnl
If =1, we asume that all the power that reaches the end of its
lifetime is replaced.

share geot for elec[BAU]=
GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C25')
share geot for elec[SCEN1]=
GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C25')
share geot for elec[SCEN2]=
GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C25')
share geot for elec[SCEN3]=
GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C25')
share geot for elec[SCEN4]=
GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C25')
share geot for elec[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C25')

Units: TWe

Share of geothermal for electricity in relation to the total potential of geothermal (including thermal uses).

"surface geot-elec MHa"[scenarios]=

"geot-elec TWe"[scenarios]/"power density geot-elec"

Units: MHa

Surface required to produce "geot TWe".

"Time 95pc TS potential geot-elec"[scenarios]=

IF THEN ELSE("Remaining potential geot-elec"[scenarios]>0.05, 0, Time)

Units: **undefined**

Time when the remaining resource availability falls bellow 5% of the techno-ecological potential, i.e. when the 95% of the techno-ecological potential is reached.

Time dmnl[scenarios](

[(1990,1990)-(2100,2100)],(1990,1990),(1991,1991),(1992,1992),(1993,1993),
(1994,1994),(1995,1995),(1996,1996),(1997,1997),(1998,1998),(1999,1999),(2000
,2000),(2001,2001),(2002,2002),(2003,2003),(2004,2004),(2005,2005),(2006,2006
),(2007,2007),(2008,2008),(2009,2009),(2010,2010),(2011,2011),(2012,2012),(
2013,2013),(2014,2014),(2015,2015),(2016,2016),(2017,2017),(2018,2018),(2019
,2019),(2020,2020),(2021,2021),(2022,2022),(2023,2023),(2024,2024),(2025,2025
),(2026,2026),(2027,2027),(2028,2028),(2029,2029),(2030,2030),(2031,2031),(
2032,2032),(2033,2033),(2034,2034),(2035,2035),(2036,2036),(2037,2037),(2038
,2038),(2039,2039),(2040,2040),(2041,2041),(2042,2042),(2043,2043),(2044,2044
),(2045,2045),(2046,2046),(2047,2047),(2048,2048),(2049,2049),(2050,2050),(
2051,2051),(2052,2052),(2053,2053),(2054,2054),(2055,2055),(2056,2056),(2057
,2057),(2058,2058),(2059,2059),(2060,2060),(2061,2061),(2062,2062),(2063,2063
),(2064,2064),(2065,2065),(2066,2066),(2067,2067),(2068,2068),(2069,2069),(
2070,2070),(2071,2071),(2072,2072),(2073,2073),(2074,2074),(2075,2075),(2076
,2076),(2077,2077),(2078,2078),(2079,2079),(2080,2080),(2081,2081),(2082,2082
),(2083,2083),(2084,2084),(2085,2085),(2086,2086),(2087,2087),(2088,2088),(
2089,2089),(2090,2090),(2091,2091),(2092,2092),(2093,2093),(2094,2094),(2095
,2095),(2096,2096),(2097,2097),(2098,2098),(2099,2099),(2100,2100))

Units: Dmnl

Vector that assigns for every year the number of that same year.

TWe per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C7')

Units: TWe/(TWh/Year)

Unit conversion (1 TWe=8760 TWh per year)

"wear geot-elec"[scenarios]=

"geot-elec TWe"[scenarios]/"life time geot-elec"

Units: TWe

Decommission of the capacity that reaches the end of its lifetime.

9. ELEC RES – Biomass & Waste

abundance electricity RES[scenarios]=

SQRT(ABS((Total FE Elec demand TWh[scenarios]-FE Elec generation from RES TWh [scenarios])/Total FE Elec demand TWh[scenarios]))

Units: **undefined**

adapt growth BioW[scenarios]=

IF THEN ELSE(Time<2012, past BioW, IF THEN ELSE(Time<2017, past BioW+(P BioW [scenarios]-past BioW)*(Time dmnl[scenarios](Time)-2012)/5, P BioW[scenarios]))

Units: 1/Year

Modeling of a soft transition from current historic annual growth to reach the policy-objective 5 years later.

BioW evol[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C34')

BioW evol[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C34')

BioW evol[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C34')

BioW evol[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C34')

BioW evol[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C34')

BioW evol[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C34')

Units: Dmnl

Annual growth in energy output as a function of past trends.

BioW TWe[scenarios]= INTEG (

new BioW TWe[scenarios]+replacement BioW[scenarios]-wear BioW[scenarios],

initial BioW TWe)

Units: TWe

Annual electricity generation.

capacity BioW[scenarios]=

BioW TWe[scenarios]/Cp BioW[scenarios]

Units: TW

Installed capacity.

check electricity[scenarios]=

(Total FE Elec demand TWh[scenarios]-Total FE Elec generation TWh[scenarios

])/Total FE Elec generation TWh[scenarios]

Units: Dmnl

If=1: demand=supply. If>0: demand>supply. If<0: demand<supply.

Variable to avoid energy oversupply caused by exogenously driven

policies.

"constrain electricity exogenous growth?"[scenarios]=

IF THEN ELSE(check electricity[scenarios]>-0.01 ,1 ,check electricity[scenarios

])

Units: Dmnl

If negative, there is oversupply of electricity. This variable

is used to constrain the exogenous growth of exogenously-driven

policies.

Cp baseload reduction[scenarios]=

MIN(1,-0.6209*(Share variable vs base load Elec generation delayed 1yr[scenarios

])^2 - 0.3998*(Share variable vs base load Elec generation delayed 1yr[scenarios

]) + 1.0222)

Units: Dmnl

Reduction of the capacity factor of the baseload plants as a function of the penetration of variables RES in the electricity generation.

Cp BioW initial=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'F8')

Units: Dmnl

Current capacity factor of BioW power plants. Source: EIA (2009).

Cp BioW[scenarios]=

Cp BioW initial*Cp baseload reduction[scenarios]

Units: **undefined**

Capacity factor of BioW power plants.

delivered BioE Electricity TWe[scenarios]=

Elec potential from BioE residues EJ[scenarios]*TWe per TWh/EJ per TWh

Units: TWe

Agricultural and forestry uses will be assumed to be mostly used in thermal applications (75%), as it currently happens (IPCC, 2007a, 2007b). The rest (25%) will be modeled in combination with MSW as an electrical generation technology.

efficiency conversion bioE residues to Elec=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C44')

Units: Dmnl

Efficiency of the transformation from bioenergy to electricity (de Castro & Carpintero et al (2014) cite 10-30% range.

EJ per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C5')

Units: EJ/TWh

Unit conversion (3.6 EJ=1000 TWh)

Elec potential from BioE residues EJ[scenarios]=

PE bioE residues for Elec EJ[scenarios]*efficiency conversion bioE residues to Elec

Units: EJ/Year

Electricity potential from bioenergy-residues.

FE Elec generation from BioW TWh[scenarios]=

BioW TWe[scenarios]/TWe per TWh

Units: TWh/Year

Annual electricity generation.

gCO2e per KWh biomass=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'E8')

Units: gCO2e/kWh

No data.

GtCO2e biomass[scenarios]=

FE Elec generation from BioW TWh[scenarios]*gCO2e per KWh biomass*GTCO2e per gCO2e *kWh per TWh

Units: GTCO2e/Year

Annual CO2e emissions.

initial BioW TWe=

initial BioW TWh*TWe per TWh

Units: TWe

Electricity generated by Bio&Waste in 1990.

initial BioW TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C58')

Units: TWh

94 TWh generated in 1990 (US EIA database).

GTCO2e per gCO2e=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C8')

Units: GTCO2e/gCO2e

Conversion between GTCO2 and gCO2 (1 GT = 1e15 g).

Historic BioW generation(

GET XLS LOOKUPS('inputs.xlsx', 'Constants', '25', 'C58'))

Units: TWh/Year

Annual historic electricity generation from biomass & waste (1990-2013). Ref: US EIA.

invest bioW Tdolar[scenarios]=

(new BioW TWe[scenarios]+replacement BioW[scenarios])*(Invest cost BioW/Cp BioW [scenarios])

Units: Tdollars/Year

Investment costs.

Invest cost BioW:INTERPOLATE::=

GET XLS DATA('inputs.xlsx', 'Parameters', '6', 'G8')

Units: Tdollars/TWe

Investments costs per TWe (without operation & maintenance) from the scenario "Energy [R]evolution 2010" (Teske et al., 2011).

kWh per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C9')

Units: kWh/TWh

Conversion between kWh and TWh (1 TWh=1e9 kWh).

life time BioW=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C8')

Units: Year

Lifetime power plants.

max BioW TWe[scenarios]=

max BioW without delivered Bio Elec TWe[scenarios]+delivered BioE Electricity TWe [scenarios]

Units: TWe

Techno-ecological potential of biomass&waste. This potential is dynamic and dependant on the potential assigned for bioenergy, and the assumed share for electricity ("delivered BioE Electricity") (1 TWe = 8760 TWh in one year).

max BioW without delivered Bio Elec TWe[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C26')

max BioW without delivered Bio Elec TWe[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C26')

max BioW without delivered Bio Elec TWe[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C26')

max BioW without delivered Bio Elec TWe[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C26')

max BioW without delivered Bio Elec TWe[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C26')

max BioW without delivered Bio Elec TWe[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C26')

Units: TWe

Techno-ecological potential of biomass&waste without bioenergy

(1 TWe = 8760 TWh in one year).

MToe per EJ=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C6')

Units: MToe/EJ

Unit conversion (1000 Mtoe=41.868 EJ)

new BioW TWe[scenarios]=

IF THEN ELSE(Time<2012, (Historic BioW generation(Time+1)-Historic BioW generation (Time))*TWe per TWh,

IF THEN ELSE(check electricity[scenarios]<-0.01, "constrain electricity exogenous growth?" [scenarios]*BioW TWe[scenarios],

adapt growth BioW[scenarios]*BioW TWe[scenarios]*Remaining potential BioW[scenarios]))

Units: TWe

New annual biomass & waste power installed (TWe).

P BioW[scenarios]=

BioW evol[scenarios]*past BioW*abundance electricity RES[scenarios]

Units: 1/Year

Annual growth in energy output demand depending on the policy of

the scenario. Other option IF THEN ELSE(Time<2035, 0.07 , P

residues[scenarios])

past BioW=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C83')

Units: 1/Year

Current growth patterns (1990-2013).

PE BioW for Elec generation EJ[scenarios]=

FE Elec generation from BioW TWh[scenarios]*EJ per TWh/efficiency conversion bioE residues to Elec

Units: EJ/Year

Annual primary energy to generate electricity (Direct Equivalent
Method).

PE BioW for Elec generation Mtoe[scenarios]=

PE BioW for Elec generation EJ[scenarios]*MToe per EJ

Units: MToe/Year

Annual primary energy to generate electricity (Direct Equivalent
Method).

PE losses BioW for Elec EJ[scenarios]=

PE BioW for Elec generation EJ[scenarios]*(1-efficiency conversion bioE residues to Elec
)

Units: EJ/Year

(Primary energy) losses due to the production of electricity
from BioW.

Remaining potential BioW[scenarios]=

(max BioW TWe[scenarios]-BioW TWe[scenarios])/max BioW TWe[scenarios]

Units: Dmnl

Remaining potential available as a fraction of unity.

replacement BioW[scenarios]=

wear BioW[scenarios]*replacement rate BioW

Units: TWe

If replacement rate=1, we asume that all the power that reaches
the end of its lifetime is replaced.

replacement rate BioW=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'D8')

Units: Dmnl

If =1, we asume that all the power that reaches the end of its
lifetime is replaced.

Time 95pc TS potential BioW[scenarios]=

IF THEN ELSE(Remaining potential BioW[scenarios]>0.05, 0, Time)

Units: **undefined**

Time when the remaining resource availability falls bellow 5% of
the techno-ecological potential, i.e. when the 95% of the
techno-ecological potential is reached.

Time dmnl[scenarios](
[(1990,1990)-(2100,2100)],(1990,1990),(1991,1991),(1992,1992),(1993,1993),
(1994,1994),(1995,1995),(1996,1996),(1997,1997),(1998,1998),(1999,1999),(2000
,2000),(2001,2001),(2002,2002),(2003,2003),(2004,2004),(2005,2005),(2006,2006
),(2007,2007),(2008,2008),(2009,2009),(2010,2010),(2011,2011),(2012,2012),(
2013,2013),(2014,2014),(2015,2015),(2016,2016),(2017,2017),(2018,2018),(2019
,2019),(2020,2020),(2021,2021),(2022,2022),(2023,2023),(2024,2024),(2025,2025
),(2026,2026),(2027,2027),(2028,2028),(2029,2029),(2030,2030),(2031,2031),(
2032,2032),(2033,2033),(2034,2034),(2035,2035),(2036,2036),(2037,2037),(2038
,2038),(2039,2039),(2040,2040),(2041,2041),(2042,2042),(2043,2043),(2044,2044
),(2045,2045),(2046,2046),(2047,2047),(2048,2048),(2049,2049),(2050,2050),(
2051,2051),(2052,2052),(2053,2053),(2054,2054),(2055,2055),(2056,2056),(2057
,2057),(2058,2058),(2059,2059),(2060,2060),(2061,2061),(2062,2062),(2063,2063
),(2064,2064),(2065,2065),(2066,2066),(2067,2067),(2068,2068),(2069,2069),(
2070,2070),(2071,2071),(2072,2072),(2073,2073),(2074,2074),(2075,2075),(2076
,2076),(2077,2077),(2078,2078),(2079,2079),(2080,2080),(2081,2081),(2082,2082
),(2083,2083),(2084,2084),(2085,2085),(2086,2086),(2087,2087),(2088,2088),(
2089,2089),(2090,2090),(2091,2091),(2092,2092),(2093,2093),(2094,2094),(2095
,2095),(2096,2096),(2097,2097),(2098,2098),(2099,2099),(2100,2100))

Units: Dmnl

Vector that assigns for every year the number of that same year.

TWe per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C7')

Units: TWe/(TWh/Year)

Unit conversion (1 TWe=8760 TWh per year)

wear BioW[scenarios]=

BioW TWe[scenarios]/life time BioW

Units: TWe

Decommission of the capacity that reachs the end of its lifetime.

10. ELEC RES – Oceanic

abundance electricity RES[scenarios]=

SQRT(ABS((Total FE Elec demand TWh[scenarios]-FE Elec generation from RES TWh [scenarios])/Total FE Elec demand TWh[scenarios]))

Units: **undefined**

adapt growth oceanic[scenarios]=

IF THEN ELSE(Time<2013, past oceanic, IF THEN ELSE(Time<2018, past oceanic +(P oceanic[scenarios]-past oceanic)*(Time dmnl[scenarios](Time)-2013)/5, P oceanic [scenarios])*abundance electricity RES[scenarios])

Units: 1/Year

Modeling of a soft transition from current historic annual growth to reach the policy-objective 5 years later.

capacity oceanic[scenarios]=

oceanic TWe[scenarios]/Cp oceanic[scenarios]

Units: TW

Installed capacity.

check electricity[scenarios]=

(Total FE Elec demand TWh[scenarios]-Total FE Elec generation TWh[scenarios])/Total FE Elec generation TWh[scenarios]

Units: Dmnl

If=1: demand=supply. If>0: demand>supply. If<0: demand<supply. Variable to avoid energy oversupply caused by exogenously driven policies.

"constrain electricity exogenous growth?"[scenarios]=

IF THEN ELSE(check electricity[scenarios]>-0.01 ,1 ,check electricity[scenarios])

Units: Dmnl

If negative, there is oversupply of electricity. This variable is used to constrain the exogenous growth of exogenously-driven policies.

Cp baseload reduction[scenarios]=

MIN(1,-0.6209*(Share variable vs base load Elec generation delayed 1yr[scenarios

])^2 - 0.3998*(Share variable vs base load Elec generation delayed 1yr[scenarios

]) + 1.0222)

Units: Dmnl

Reduction of the capacity factor of the baseload plants as a

function of the penetration of variables RES in the electricity

generation.

Cp oceanic[scenarios]=

Cp oceanic initial*Cp baseload reduction[scenarios]

Units: **undefined**

Capacity factor of oceanic power plants devices.

Cp oceanic initial=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'F9')

Units: Dmnl

Capacity factor of oceanic power plants devices. We assume a 90%.

EJ per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C5')

Units: EJ/TWh

Unit conversion (3.6 EJ=1000 TWh)

FE Elec generation from oceanic TWh[scenarios]=

oceanic TWe[scenarios]/TWe per TWh

Units: TWh/Year

Annual electricity generation.

gCO2e per KWh oceanic=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'E9')

Units: gCO2e/kWh

CO2eq emissions. Source Arvesen et al (2011). 14-21.7 gCO2e/KWh

GtCO2e oceanic[scenarios]=

FE Elec generation from oceanic TWh[scenarios]*gCO2e per KWh oceanic*GTCO2e per gCO2e

*kWh per TWh

Units: GTCO2e/Year

Annual CO2e emissions.

GTCO2e per gCO2e=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C8')

Units: GTCO2e/gCO2e

Conversion between GTCO2 and gCO2 (1 GT = 1e15 g).

Historic oceanic generation(

GET XLS LOOKUPS('inputs.xlsx', 'Constants', '25', 'C59'))

Units: TWh/Year

Annual historic electricity generation from oceanic energy

(2000-2014). Ref: IRENA db.

initial oceanic TWe=

initial oceanic TWh*TWe per TWh

Units: TWe

Electricity generated by oceanic RES in 1990.

initial oceanic TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C59')

Units: TWh

0 TWh generated in 1990 (IRENA).

Invest cost oceanic:INTERPOLATE::=

GET XLS DATA('inputs.xlsx', 'Parameters', '6', 'G9')

Units: Tdollars/TWe

Investments costs per TWe (without operation & maintenance) from

the scenario "Energy [R]evolution 2010" (Teske et al., 2011).

invest oceanic Tdolar[scenarios]=

(new oceanic TWe[scenarios]+replacement oceanic[scenarios])*(Invest cost oceanic

/Cp oceanic[scenarios])

Units: Tdollars/Year

Investment costs.

kWh per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C9')

Units: kWh/TWh

Conversion between kWh and TWh (1 TWh=1e9 kWh).

life time oceanic=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C9')

Units: Year

Lifetime power plants.

max oceanic TWe[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C27')

max oceanic TWe[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C27')

max oceanic TWe[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C27')

max oceanic TWe[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C27')

max oceanic TWe[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C27')

max oceanic TWe[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C27')

Units: TWe

Techno-ecological potential of oceanic (1 TWe = 8760 TWh in one year).

new oceanic TWe[scenarios]=

IF THEN ELSE(Time<2013, (Historic oceanic generation(Time+1)-Historic oceanic generation (Time))*TWe per TWh,

IF THEN ELSE(check electricity[scenarios]<-0.01, "constrain electricity exogenous growth?" [scenarios]*oceanic TWe[scenarios],

adapt growth oceanic[scenarios]*oceanic TWe[scenarios]*Remaining potential oceanic [scenarios]))

Units: TWe

New annual oceanic electric power installed (TWe).

oceanic TWe[scenarios]= INTEG (

new oceanic TWe[scenarios]+replacement oceanic[scenarios]-wear oceanic[scenarios],

initial oceanic TWe)

Units: TWe/Year

Annual electricity generation.

P oceanic[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C35')

P oceanic[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C35')

P oceanic[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C35')

P oceanic[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C35')

P oceanic[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C35')

P oceanic[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C35')

Units: 1/Year

Annual growth in energy output demand depending on the policy of the scenario.

past oceanic=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C84')

Units: 1/Year

Current growth patterns (2000-2014).

PE oceanic for Elec generation EJ[scenarios]=

FE Elec generation from oceanic TWh[scenarios]*EJ per TWh

Units: EJ/Year

Annual primary energy to generate electricity (Direct Equivalent Method).

Remaining potential oceanic[scenarios]=

(max oceanic TWe[scenarios]-oceanic TWe[scenarios])/max oceanic TWe[scenarios
]

Units: Dmnl

Remaining potential available as a fraction of unity.

replacement oceanic[scenarios]=

wear oceanic[scenarios]*replacement rate oceanic

Units: TWe/Year

If replacement rate=1, we asume that all the power that reaches the end of its lifetime is replaced.

replacement rate oceanic=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'D9')

Units: Dmnl

If =1, we asume that all the power that reaches the end of its lifetime is replaced.

Time 95pc TS potential oceanic[scenarios]=

IF THEN ELSE(Remaining potential oceanic[scenarios]>0.05, 0, Time)

Units: **undefined**

Time when the remaining resource availability falls bellow 5% of the techno-ecological potential, i.e. when the 95% of the techno-ecological potential is reached.

Time dmnl[scenarios](

[(1990,1990)-(2100,2100)],(1990,1990),(1991,1991),(1992,1992),(1993,1993),
(1994,1994),(1995,1995),(1996,1996),(1997,1997),(1998,1998),(1999,1999),(2000
,2000),(2001,2001),(2002,2002),(2003,2003),(2004,2004),(2005,2005),(2006,2006
),(2007,2007),(2008,2008),(2009,2009),(2010,2010),(2011,2011),(2012,2012),(
2013,2013),(2014,2014),(2015,2015),(2016,2016),(2017,2017),(2018,2018),(2019
,2019),(2020,2020),(2021,2021),(2022,2022),(2023,2023),(2024,2024),(2025,2025
),(2026,2026),(2027,2027),(2028,2028),(2029,2029),(2030,2030),(2031,2031),(
2032,2032),(2033,2033),(2034,2034),(2035,2035),(2036,2036),(2037,2037),(2038
,2038),(2039,2039),(2040,2040),(2041,2041),(2042,2042),(2043,2043),(2044,2044
),(2045,2045),(2046,2046),(2047,2047),(2048,2048),(2049,2049),(2050,2050),(
2051,2051),(2052,2052),(2053,2053),(2054,2054),(2055,2055),(2056,2056),(2057
,2057),(2058,2058),(2059,2059),(2060,2060),(2061,2061),(2062,2062),(2063,2063
),(2064,2064),(2065,2065),(2066,2066),(2067,2067),(2068,2068),(2069,2069),(
2070,2070),(2071,2071),(2072,2072),(2073,2073),(2074,2074),(2075,2075),(2076
,2076),(2077,2077),(2078,2078),(2079,2079),(2080,2080),(2081,2081),(2082,2082
),(2083,2083),(2084,2084),(2085,2085),(2086,2086),(2087,2087),(2088,2088),(
2089,2089),(2090,2090),(2091,2091),(2092,2092),(2093,2093),(2094,2094),(2095
,2095),(2096,2096),(2097,2097),(2098,2098),(2099,2099),(2100,2100))

Units: Dmnl

Vector that assigns for every year the number of that same year.

TWe per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C7')

Units: TWe/(TWh/Year)

Unit conversion (1 TWe=8760 TWh per year)

wear oceanic[scenarios]=

oceanic TWe[scenarios]/life time oceanic

Units: TWe/Year

Decommission of the capacity that reachs the end of its lifetime.

11. ELEC RES – Onshore wind

abundance electricity RES[scenarios]=

SQRT(ABS((Total FE Elec demand TWh[scenarios]-FE Elec generation from RES TWh [scenarios])/Total FE Elec demand TWh[scenarios]))

Units: **undefined**

adapt growth onshore wind[scenarios]=

IF THEN ELSE(Time<2014, past onshore wind, IF THEN ELSE(Time<2019, past onshore wind +(P onshore wind[scenarios]-past onshore wind)*(Time dmnl[scenarios](Time)-2014)/5, P onshore wind[scenarios])*abundance electricity RES[scenarios])

Units: 1/Year

Modeling of a soft transition from current historic annual growth to reach the policy-objective 5 years later.

capacity onshore wind[scenarios]=

onshore wind TWe[scenarios]/Cp onshore wind

Units: TW

Installed capacity.

check electricity[scenarios]=

(Total FE Elec demand TWh[scenarios]-Total FE Elec generation TWh[scenarios])/Total FE Elec generation TWh[scenarios]

Units: Dmnl

If=1: demand=supply. If>0: demand>supply. If<0: demand<supply.

Variable to avoid energy oversupply caused by exogenously driven policies.

"constrain electricity exogenous growth?"[scenarios]=

IF THEN ELSE(check electricity[scenarios]>-0.01 ,1 ,check electricity[scenarios
])

Units: Dmnl

If negative, there is oversupply of electricity. This variable is used to constrain the exogenous growth of exogenously-driven policies.

Cp onshore wind=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'F10')

Units: Dmnl

Capacity factor of onshore wind. Source: Boccard (2009).

EJ per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C5')

Units: EJ/TWh

Unit conversion (3.6 EJ=1000 TWh)

FE Elec generation from onshore wind TWh[scenarios]=

onshore wind TWe[scenarios]/TWe per TWh

Units: TWh/Year

Annual electricity generation.

gCO2e per KWh onshore wind=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'E10')

Units: gCO2e/kWh

CO2eq emissions. Source Arvesen et al (2011). 2.8-7.4 gCO2e/KWh

GtCO2e onshore wind[scenarios]=

FE Elec generation from onshore wind TWh[scenarios]*gCO2e per KWh onshore wind
*GTCO2e per gCO2e*kWh per TWh

Units: GTCO2e/Year

Annual CO2e emissions.

GTCO2e per gCO2e=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C8')

Units: GTCO2e/gCO2e

Conversion between GTCO2 and gCO2 (1 GT = 1e15 g).

Historic onshore wind generation(

GET XLS LOOKUPS('inputs.xlsx', 'Constants', '25', 'C60'))

Units: TWh/Year

Annual historic electricity generation from onshore wind

(1990-2015). Ref: IRENA db & BP (2016).

initial onshore wind TWe=

initial onshore wind TWh*TWe per TWh

Units: TWe

Electricity generated by onshore wind in 1990.

initial onshore wind TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C60')

Units: TWh

3.6 TWh generated in 1990 (BP 2016).

Invest cost onshore wind:INTERPOLATE::=

GET XLS DATA('inputs.xlsx', 'Parameters', '6', 'G10')

Units: Tdollars/TWe

Investments costs per TWe (without operation & maintenance) from

the scenario "Energy [R]evolution 2010" (Teske et al., 2011).

invest onshore wind Tdolar[scenarios]=

(new onshore wind TWe[scenarios]+replacement onshore wind[scenarios])*(Invest cost onshore wind /Cp onshore wind)

Units: Tdollars/Year

Investment costs.

kWh per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C9')

Units: kWh/TWh

Conversion between kWh and TWh (1 TWh=1e9 kWh).

life time onshore wind=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C10')

Units: Year

Lifetime power plants.

max offshore wind TWe[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C29')

max offshore wind TWe[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C29')

max offshore wind TWe[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C29')

max offshore wind TWe[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C29')

max offshore wind TWe[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C29')

max offshore wind TWe[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C29')

Units: TWe

Techno-ecological potential of offshore wind (1 TWe = 8760 TWh in one year).

max onshore wind TWe[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C28')

max onshore wind TWe[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C28')

max onshore wind TWe[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C28')

max onshore wind TWe[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C28')

max onshore wind TWe[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C28')

max onshore wind TWe[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C28')

Units: TWe

Techno-ecological potential of onshore wind (1 TWe = 8760 TWh in one year).

new onshore wind TWe[scenarios]=

IF THEN ELSE(Time<2014, (Historic onshore wind generation(Time+1)-Historic onshore wind generation (Time))*TWe per TWh,

IF THEN ELSE(check electricity[scenarios]<-0.01, "constrain electricity exogenous growth?" [scenarios]*onshore wind TWe[scenarios],

adapt growth onshore wind[scenarios]*onshore wind TWe[scenarios]*Remaining potential onshore wind [scenarios]))

Units: TWe

New annual wind electric power installed (TWe). We use wind as a

proxy to estimate the extra investment to cope with variable

Elec RES (see Technical Report).

offshore wind TWe[scenarios]= INTEG (

new offshore wind TWe[scenarios]+replacement offshore wind[scenarios]-wear offshore wind [scenarios],

initial offshore wind TWe)

Units: TWe

Annual electricity generation.

onshore wind TWe[scenarios]= INTEG (

new onshore wind TWe[scenarios]+replacement onshore wind[scenarios]-wear onshore wind [scenarios],

initial onshore wind TWe)

Units: TWe

Annual electricity generation.

P onshore wind[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C36')

P onshore wind[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C36')

P onshore wind[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C36')

P onshore wind[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C36')

P onshore wind[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C36')

P onshore wind[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C36')

Units: 1/Year

Annual growth in energy output demand depending on the policy of the scenario.

past onshore wind=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C85')

Units: 1/Year

Current growth patterns (1990-2015).

PE onshore wind for Elec generation EJ[scenarios]=

FE Elec generation from onshore wind TWh[scenarios]*EJ per TWh

Units: EJ/Year

Annual primary energy to generate electricity (Direct Equivalent Method).

power density onshore wind=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'B10')

Units: TWe/MHa

Power density: 2.5 We/m2 (de Castro et al., 2013b; Smil, 2015)

Remaining potential onshore wind[scenarios]=

(max onshore wind TWe[scenarios]-onshore wind TWe[scenarios])/max onshore wind TWe [scenarios]

Units: Dmnl

Remaining potential available as a fraction of unity.

Remaining potential wind[scenarios]=

((max onshore wind TWe[scenarios]+max offshore wind TWe[scenarios])-(onshore wind TWe [scenarios]+offshore wind TWe[scenarios]))/(max onshore wind TWe[scenarios] +max offshore wind TWe[scenarios])

Units: **undefined**

Total wind remaining potential available as a fraction of unity.

replacement onshore wind[scenarios]=

replacement rate onshore wind*wear onshore wind[scenarios]

Units: TWe

If replacement rate=1, we asume that all the power that reaches
the end of its lifetime is replaced.

replacement rate onshore wind=
GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'D10')

Units: Dmnl

If =1, we asume that all the power that reaches the end of its
lifetime is replaced.

surface onshore wind[scenarios]=
onshore wind TWe[scenarios]/power density onshore wind

Units: MHa

Surface required to produce "onshore wind TWe".

Time 95pc TS potential onshore wind[scenarios]=
IF THEN ELSE(Remaining potential onshore wind[scenarios]>0.05, 0, Time)

Units: Year

Time when the remaining resource availability falls bellow 5% of
the techno-ecological potential, i.e. when the 95% of the
techno-ecological potential is reached.

Time 95pc TS potential wind[scenarios]=
IF THEN ELSE(Remaining potential wind[scenarios]>0.05, 0, Time)

Units: Year

Time when the remaining resource availability falls bellow 5% of
the techno-ecological potential, i.e. when the 95% of the
techno-ecological potential is reached.

Time dmnl[scenarios](
[(1990,1990)-(2100,2100)],(1990,1990),(1991,1991),(1992,1992),(1993,1993),
(1994,1994),(1995,1995),(1996,1996),(1997,1997),(1998,1998),(1999,1999),(2000
,2000),(2001,2001),(2002,2002),(2003,2003),(2004,2004),(2005,2005),(2006,2006
),(2007,2007),(2008,2008),(2009,2009),(2010,2010),(2011,2011),(2012,2012),(
2013,2013),(2014,2014),(2015,2015),(2016,2016),(2017,2017),(2018,2018),(2019
,2019),(2020,2020),(2021,2021),(2022,2022),(2023,2023),(2024,2024),(2025,2025
),(2026,2026),(2027,2027),(2028,2028),(2029,2029),(2030,2030),(2031,2031),(

2032,2032),(2033,2033),(2034,2034),(2035,2035),(2036,2036),(2037,2037),(2038
,2038),(2039,2039),(2040,2040),(2041,2041),(2042,2042),(2043,2043),(2044,2044
),(2045,2045),(2046,2046),(2047,2047),(2048,2048),(2049,2049),(2050,2050),(
2051,2051),(2052,2052),(2053,2053),(2054,2054),(2055,2055),(2056,2056),(2057
,2057),(2058,2058),(2059,2059),(2060,2060),(2061,2061),(2062,2062),(2063,2063
),(2064,2064),(2065,2065),(2066,2066),(2067,2067),(2068,2068),(2069,2069),(
2070,2070),(2071,2071),(2072,2072),(2073,2073),(2074,2074),(2075,2075),(2076
,2076),(2077,2077),(2078,2078),(2079,2079),(2080,2080),(2081,2081),(2082,2082
),(2083,2083),(2084,2084),(2085,2085),(2086,2086),(2087,2087),(2088,2088),(
2089,2089),(2090,2090),(2091,2091),(2092,2092),(2093,2093),(2094,2094),(2095
,2095),(2096,2096),(2097,2097),(2098,2098),(2099,2099),(2100,2100))

Units: Dmnl

Vector that assigns for every year the number of that same year.

TWe per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C7')

Units: TWe/(TWh/Year)

Unit conversion (1 TWe=8760 TWh per year)

wear onshore wind[scenarios]=

onshore wind TWe[scenarios]/life time onshore wind

Units: TWe

Decommission of the capacity that reachs the end of its lifetime.

12. ELEC RES- Offshore wind

abundance electricity RES[scenarios]=

SQRT(ABS((Total FE Elec demand TWh[scenarios]-FE Elec generation from RES TWh [scenarios])/Total FE Elec demand TWh[scenarios]))

Units: **undefined**

adapt growth offshore wind[scenarios]=

IF THEN ELSE(Time<2013, past offshore wind, IF THEN ELSE(Time<2018, past offshore wind
+(P offshore wind[scenarios]-past offshore wind)*(Time dmnl[scenarios](Time
)-2013)/5, P offshore wind[scenarios])*abundance electricity RES[scenarios]
)

Units: 1/Year

Modeling of a soft transition from current historic annual
growth to reach the policy-objective 5 years later.

capacity offshore wind[scenarios]=
offshore wind TWe[scenarios]/Cp offshore wind
Units: TW
Installed capacity.

check electricity[scenarios]=
(Total FE Elec demand TWh[scenarios]-Total FE Elec generation TWh[scenarios
])/Total FE Elec generation TWh[scenarios]
Units: Dmnl
If=1: demand=supply. If>0: demand>supply. If<0: demand<supply.
Variable to avoid energy oversupply caused by exogenously driven
policies.

"constrain electricity exogenous growth?"[scenarios]=
IF THEN ELSE(check electricity[scenarios]>-0.01 ,1 ,check electricity[scenarios
])
Units: Dmnl
If negative, there is oversupply of electricity. This variable
is used to constrain the exogenous growth of exogenously-driven
policies.

Cp offshore wind=
GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'F12')
Units: Dmnl
Capacity factor of offshore wind. We assume that offshore wind
has a +30% higher Cp than onshore wind.

EJ per TWh=
GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C5')
Units: EJ/TWh
Unit conversion (3.6 EJ=1000 TWh)

FE Elec generation from offshore wind TWh[scenarios]=
offshore wind TWe[scenarios]/TWe per TWh

Units: TWh/Year

Annual electricity generation.

gCO2e per KWh offshore wind=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'E12')

Units: gCO2e/kWh

CO2e emissions of offshore wind production; same as for onshore
wind.

GtCO2e offshore wind[scenarios]=

FE Elec generation from offshore wind TWh[scenarios]*gCO2e per KWh offshore wind
*GTCO2e per gCO2e*kWh per TWh

Units: GTCO2e/Year

Annual CO2e emissions.

GTCO2e per gCO2e=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C8')

Units: GTCO2e/gCO2e

Conversion between GTCO2 and gCO2 (1 GT = 1e15 g).

Historic offshore wind generation(

GET XLS LOOKUPS('inputs.xlsx', 'Constants', '25', 'C61'))

Units: TWh/Year

Annual historic electricity generation from offshore wind
(2000-2015). Ref: IRENA.

initial offshore wind TWe=

initial offshore wind TWh*TWe per TWh

Units: TWe

Electricity generated by offshore wind in 1990 (IRENA).

initial offshore wind TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C61')

Units: TWh

0 TWh generated in 1990 (IRENA).

Invest cost offshore wind:INTERPOLATE::=

GET XLS DATA('inputs.xlsx', 'Parameters', '6', 'G12')

Units: Tdollars/TWe

Investments costs per TWe (without operation & maintenance) from

the scenario "Energy [R]evolution 2010" (Teske et al., 2011).

invest offshore wind Tdolar[scenarios]=

(new offshore wind TWe[scenarios]+replacement offshore wind[scenarios])*(Invest cost offshore wind /Cp offshore wind)

Units: Tdollars/Year

Investment costs.

kWh per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C9')

Units: kWh/TWh

Conversion between kWh and TWh (1 TWh=1e9 kWh).

life time offshore wind=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C12')

Units: Year

Lifetime power plants.

max offshore wind TWe[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C29')

max offshore wind TWe[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C29')

max offshore wind TWe[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C29')

max offshore wind TWe[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C29')

max offshore wind TWe[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C29')

max offshore wind TWe[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C29')

Units: TWe

Techno-ecological potential of offshore wind (1 TWe = 8760 TWh in one year).

new offshore wind TWe[scenarios]=

IF THEN ELSE(Time<2013, (Historic offshore wind generation(Time+1)-Historic offshore wind generation (Time))*TWe per TWh,

IF THEN ELSE(check electricity[scenarios]<-0.01, "constrain electricity exogenous growth?"[scenarios]*offshore wind TWe[scenarios],

adapt growth offshore wind[scenarios]*offshore wind TWe[scenarios]*Remaining potential offshore wind [scenarios]))

Units: TWe

New annual wind electric power installed (TWe).

offshore wind TWe[scenarios]= INTEG (

new offshore wind TWe[scenarios]+replacement offshore wind[scenarios]-wear offshore wind [scenarios],

initial offshore wind TWe)

Units: TWe

Annual electricity generation.

"overcapacity vs. intermittent RES penetration 0"[scenarios]=

MAX(1, 0.9599*EXP(0.8938*Share variable vs base load Elec generation delayed 1yr [scenarios]))

Units: Dmnl

Total overcapacity vs. intermittent RES penetration in

electricity generation.

P offshore wind[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C37')

P offshore wind[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C37')

P offshore wind[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C37')

P offshore wind[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C37')

P offshore wind[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C37')

P offshore wind[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C37')

Units: 1/Year

Annual growth in energy output demand depending on the policy of
the scenario.

past offshore wind=
GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C88')
Units: 1/Year
Current growth patterns (2000-2014).

PE offshore wind for Elec generation EJ[scenarios]=
FE Elec generation from offshore wind TWh[scenarios]*EJ per TWh
Units: EJ/Year
Annual primary energy to generate electricity (Direct Equivalent
Method).

power density offshore wind=
GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'B12')
Units: TWe/MHa
Power density: 1 We/m2 (de Castro et al., 2013b; Smil, 2015)

Remaining potential offshore wind[scenarios]=
(max offshore wind TWe[scenarios]-offshore wind TWe[scenarios])/max offshore wind TWe
[scenarios]
Units: Dmnl
Remaining potential available as a fraction of unity.

replacement offshore wind[scenarios]=
replacement rate offshore wind*wear offshore wind[scenarios]
Units: TWe
If replacement rate=1, we asume that all the power that reaches
the end of its lifetime is replaced.

replacement rate offshore wind=
GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'D12')
Units: Dmnl
If =1, we asume that all the power that reaches the end of its
lifetime is replaced.

surface offshore wind[scenarios]=

offshore wind TWe[scenarios]/power density offshore wind

Units: MHa

Marine surface required to produce "offshore wind TWe".

Time 95pc TS potential offshore wind[scenarios]=

IF THEN ELSE(Remaining potential offshore wind[scenarios]>0.05, 0, Time)

Units: Year

Time when the remaining resource availability falls bellow 5% of

the techno-ecological potential, i.e. when the 95% of the

techno-ecological potential is reached.

Time dmnl[scenarios](

[(1990,1990)-(2100,2100)],(1990,1990),(1991,1991),(1992,1992),(1993,1993),
(1994,1994),(1995,1995),(1996,1996),(1997,1997),(1998,1998),(1999,1999),(2000
,2000),(2001,2001),(2002,2002),(2003,2003),(2004,2004),(2005,2005),(2006,2006
),(2007,2007),(2008,2008),(2009,2009),(2010,2010),(2011,2011),(2012,2012),(
2013,2013),(2014,2014),(2015,2015),(2016,2016),(2017,2017),(2018,2018),(2019
,2019),(2020,2020),(2021,2021),(2022,2022),(2023,2023),(2024,2024),(2025,2025
),(2026,2026),(2027,2027),(2028,2028),(2029,2029),(2030,2030),(2031,2031),(
2032,2032),(2033,2033),(2034,2034),(2035,2035),(2036,2036),(2037,2037),(2038
,2038),(2039,2039),(2040,2040),(2041,2041),(2042,2042),(2043,2043),(2044,2044
),(2045,2045),(2046,2046),(2047,2047),(2048,2048),(2049,2049),(2050,2050),(
2051,2051),(2052,2052),(2053,2053),(2054,2054),(2055,2055),(2056,2056),(2057
,2057),(2058,2058),(2059,2059),(2060,2060),(2061,2061),(2062,2062),(2063,2063
),(2064,2064),(2065,2065),(2066,2066),(2067,2067),(2068,2068),(2069,2069),(
2070,2070),(2071,2071),(2072,2072),(2073,2073),(2074,2074),(2075,2075),(2076
,2076),(2077,2077),(2078,2078),(2079,2079),(2080,2080),(2081,2081),(2082,2082
),(2083,2083),(2084,2084),(2085,2085),(2086,2086),(2087,2087),(2088,2088),(
2089,2089),(2090,2090),(2091,2091),(2092,2092),(2093,2093),(2094,2094),(2095
,2095),(2096,2096),(2097,2097),(2098,2098),(2099,2099),(2100,2100))

Units: Dmnl

Vector that assigns for every year the number of that same year.

TWe per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C7')

Units: TWe/(TWh/Year)

Unit conversion (1 TWe=8760 TWh per year)

wear offshore wind[scenarios]=

offshore wind TWe[scenarios]/life time offshore wind

Units: TWe

Decommission of the capacity that reachs the end of its lifetime.

13. ELEC RES – Solar

abundance electricity RES[scenarios]=

SQRT(ABS((Total FE Elec demand TWh[scenarios]-FE Elec generation from RES TWh [scenarios])/Total FE Elec demand TWh[scenarios]))

Units: **undefined**

adapt growth solar[scenarios]=

IF THEN ELSE(Time<2014, past solar, IF THEN ELSE(Time<2019, past solar+(P solar [scenarios]-past solar)*(Time dmnl[scenarios](Time)-2014)/5, P solar[scenarios])*abundance electricity RES[scenarios])

Units: 1/Year

Modeling of a soft transition from current historic annual growth to reach the policy-objective 5 years later.

capacity solar[scenarios]=

solar TWe[scenarios]/Cp solar

Units: TW

Installed capacity.

check electricity[scenarios]=

(Total FE Elec demand TWh[scenarios]-Total FE Elec generation TWh[scenarios])/Total FE Elec generation TWh[scenarios]

Units: Dmnl

If=1: demand=supply. If>0: demand>supply. If<0: demand<supply. Variable to avoid energy oversupply caused by exogenously driven policies.

"constrain electricity exogenous growth?"[scenarios]=

IF THEN ELSE(check electricity[scenarios]>-0.01 ,1 ,check electricity[scenarios])

Units: Dmnl

If negative, there is oversupply of electricity. This variable
is used to constrain the exogenous growth of exogenously-driven
policies.

Cp solar=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'F11')

Units: Dmnl

Capacity factor of solar power plants. Source: Prieto & Hall
(2013).

EJ per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C5')

Units: EJ/TWh

Unit conversion (3.6 EJ=1000 TWh)

FE Elec generation from solar TWh[scenarios]=

solar TWe[scenarios]/TWe per TWh

Units: TWh/Year

Annual electricity generation.

gCO2e per KWh solar=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'E11')

Units: gCO2e/kWh

CO2eq emissions. Source Arvesen et al (2011). PV: 19-59 // CSP:
8.5-11.3 gCO2e/KWh (1 g/KWh = 0.001 Gt/TWh)

GtCO2e solar[scenarios]=

FE Elec generation from solar TWh[scenarios]*gCO2e per KWh solar*GTCO2e per gCO2e
*kWh per TWh

Units: GTCO2e

Annual CO2e emissions.

GTCO2e per gCO2e=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C8')

Units: GTCO2e/gCO2e

Conversion between GTCO2 and gCO2 (1 GT = 1e15 g).

Historic solar generation(

GET XLS LOOKUPS('inputs.xlsx', 'Constants', '25', 'C62'))

Units: TWh/Year

Annual historic electricity generation from solar technologies

(1990-2015). Ref: BP (2016).

initial solar TWe=

initial solar TWh*TWe per TWh

Units: TWe

Electricity generated by solar technologies in 1990 (BP 2016)..

initial solar TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C62')

Units: TWh

0.4 TWh generated by solar technologies in 1990 (BP 2016).

Invest cost solar:INTERPOLATE::=

GET XLS DATA('inputs.xlsx', 'Parameters', '6', 'G11')

Units: Tdollars/TWe

Investments costs per TWe (without operation & maintenance) from

the scenario "Energy [R]evolution 2010" (Teske et al., 2011).

aThe solar investment cost is maintained constant after 2030

since we judge it to be too optimistic that the solar

technologies will manage to be less expensive than wind. In

fact, in recent years, the price of solar modules has fallen

significantly due to efficiency improvements but also to dumping

and excess capacity effects in the crisis.

invest solar Tdolar[scenarios]=

(new solar TWe[scenarios]+replacement solar[scenarios])*(Invest cost solar

/Cp solar)

Units: Tdollars/Year

Investment costs.

kWh per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C9')

Units: kWh/TWh

Conversion between kWh and TWh (1 TWh=1e9 kWh).

life time solar=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C11')

Units: Year

Lifetime power plants.

max solar on land Mha[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C30')

max solar on land Mha[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C30')

max solar on land Mha[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C30')

max solar on land Mha[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C30')

max solar on land Mha[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C30')

max solar on land Mha[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C30')

Units: MHa

Assumed land availability for solar power plants.

max solar on land TWe[scenarios]=

max solar on land Mha[scenarios]*power density solar

Units: TWe

Techno-ecological potential of solar on land (All technologies aggregated). This potential is dependant on the assumed land availability for solar power plants ("max solar MHa") and the power density (1 TWe = 8760 TWh in one year).

MToe per EJ=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C6')

Units: MToe/EJ

Unit conversion (1000 Mtoe=41.868 EJ)

new solar TWe[scenarios]=

IF THEN ELSE(Time<2014, (Historic solar generation(Time+1)-Historic solar generation (Time))*TWe per TWh,

IF THEN ELSE(check electricity[scenarios]<-0.01, "constrain electricity exogenous growth?" [scenarios]*solar TWe[scenarios],

adapt growth solar[scenarios]*solar TWe[scenarios]*Remaining potential solar on land [scenarios]))

Units: TWe

New annual hydro electric power installed (TWe).

P solar[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C38')

P solar[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C38')

P solar[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C38')

P solar[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C38')

P solar[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C38')

P solar[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C38')

Units: 1/Year

Annual growth in energy output demand depending on the policy of the scenario.

past solar=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C86')

Units: 1/Year

Current growth patterns (2000-2015).

PE solar for Elec generation EJ[scenarios]=

FE Elec generation from solar TWh[scenarios]*EJ per TWh

Units: EJ/Year

Annual primary energy to generate electricity (Direct Equivalent Method).

power density solar=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'B11')

Units: TWe/MHa

Power density: 3.3 We/m2 (de Castro et al., 2013b; Smil, 2015)

Remaining potential solar on land[scenarios]=

(max solar on land TWe[scenarios]-solar TWe[scenarios])/max solar on land TWe [scenarios]

Units: Dmnl

Remaining potential available as a fraction of unity.

replacement rate solar=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'D11')

Units: Dmnl

If =1, we asume that all the power that reaches the end of its lifetime is replaced.

replacement solar[scenarios]=

wear solar[scenarios]*replacement rate solar

Units: TWe

If replacement rate=1, we asume that all the power that reaches the end of its lifetime is replaced.

solar TWe[scenarios]= INTEG (

new solar TWe[scenarios]+replacement solar[scenarios]-wear solar[scenarios],

initial solar TWe)

Units: TWe

Annual electricity generation.

surface MHa solar[scenarios]=

solar TWe[scenarios]/power density solar

Units: MHa

Surface required to produce "solar TWe".

Time 95pc TS potential solar on land[scenarios]=

IF THEN ELSE(Remaining potential solar on land[scenarios]>0.05, 0, Time)

Units: Year

Time when the remaining resource availability falls bellow 5% of
the techno-ecological potential, i.e. when the 95%
techno-ecological potential is reached.

Time dmnl[scenarios](
[(1990,1990)-(2100,2100)],(1990,1990),(1991,1991),(1992,1992),(1993,1993),
(1994,1994),(1995,1995),(1996,1996),(1997,1997),(1998,1998),(1999,1999),(2000
,2000),(2001,2001),(2002,2002),(2003,2003),(2004,2004),(2005,2005),(2006,2006
),(2007,2007),(2008,2008),(2009,2009),(2010,2010),(2011,2011),(2012,2012),(
2013,2013),(2014,2014),(2015,2015),(2016,2016),(2017,2017),(2018,2018),(2019
,2019),(2020,2020),(2021,2021),(2022,2022),(2023,2023),(2024,2024),(2025,2025
),(2026,2026),(2027,2027),(2028,2028),(2029,2029),(2030,2030),(2031,2031),(
2032,2032),(2033,2033),(2034,2034),(2035,2035),(2036,2036),(2037,2037),(2038
,2038),(2039,2039),(2040,2040),(2041,2041),(2042,2042),(2043,2043),(2044,2044
),(2045,2045),(2046,2046),(2047,2047),(2048,2048),(2049,2049),(2050,2050),(
2051,2051),(2052,2052),(2053,2053),(2054,2054),(2055,2055),(2056,2056),(2057
,2057),(2058,2058),(2059,2059),(2060,2060),(2061,2061),(2062,2062),(2063,2063
),(2064,2064),(2065,2065),(2066,2066),(2067,2067),(2068,2068),(2069,2069),(
2070,2070),(2071,2071),(2072,2072),(2073,2073),(2074,2074),(2075,2075),(2076
,2076),(2077,2077),(2078,2078),(2079,2079),(2080,2080),(2081,2081),(2082,2082
),(2083,2083),(2084,2084),(2085,2085),(2086,2086),(2087,2087),(2088,2088),(
2089,2089),(2090,2090),(2091,2091),(2092,2092),(2093,2093),(2094,2094),(2095
,2095),(2096,2096),(2097,2097),(2098,2098),(2099,2099),(2100,2100))
Units: Dmnl
Vector that assigns for every year the number of that same year.

TWe per TWh=
GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C7')
Units: TWe/(TWh/Year)
Unit conversion (1 TWe=8760 TWh per year)

wear solar[scenarios]=
solar TWe[scenarios]/life time solar
Units: TWe
Decommission of the capacity that reachs the end of its lifetime.

14. ELEC RES – extra costs from variability

Balancing costs[scenarios]=

(Balancing costs ref(Share variable Elec generation[scenarios]))/1000

Units: Tdollars/TWh

Cost adapting data from [Holttinen2011]. 2011 T$ / TWh produced.

Balancing costs ref(

GET XLS LOOKUPS('inputs.xlsx', 'Parameters', '22' , 'B23'))

Units: Tdollars/TWh

Balancing costs adapting data from Holttinen et al (2011).

Cp baseload reduction[scenarios]=

MIN(1,-0.6209*(Share variable vs base load Elec generation delayed 1yr[scenarios
])^2 - 0.3998*(Share variable vs base load Elec generation delayed 1yr[scenarios
]) + 1.0222)

Units: Dmnl

Reduction of the capacity factor of the baseload plants as a

function of the penetration of variables RES in the electricity

generation.

Cp onshore wind=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'F10')

Units: Dmnl

Capacity factor of onshore wind. Source: Boccard (2009).

cumulated invest E grid[scenarios]= INTEG (

extra monet invest to cope with variable Elec RES[scenarios],

0)

Units: Tdollars

"Elec generation base-load from RES TWh"[scenarios]=

FE Elec generation from BioW TWh[scenarios]+FE Elec generation from geot TWh
[scenarios]+FE Elec generation from hydro TWh[scenarios]+FE Elec generation from oceanic TWh
[scenarios]

Units: TWh/Year

Base-load electricity generation from RES.

Elec generation variable from RES TWh[scenarios]=

FE Elec generation from solar TWh[scenarios]+FE Elec generation from onshore wind TWh [scenarios]+FE Elec generation from offshore wind TWh[scenarios]

Units: TWh/Year

Variable electricity generation from RES.

extra monet invest to cope with variable Elec RES[scenarios]=

(FE Elec generation from onshore wind TWh[scenarios]+FE Elec generation from offshore wind TWh [scenarios])*Balancing costs

[scenarios]+new onshore wind TWe[scenarios]*Grid reinforcement costs[scenarios]

Units: Tdollars/Year

Annual additional monetary investment to cope with the intermittency of RES (taking wind as a proxy) including balancing and grid reinforcement costs.

FE Elec generation from BioW TWh[scenarios]=

BioW TWe[scenarios]/TWe per TWh

Units: TWh/Year

Annual electricity generation.

FE Elec generation from geot TWh[scenarios]=

"geot-elec TWe"[scenarios]/TWe per TWh

Units: TWh/Year

Annual electricity generation.

FE Elec generation from hydro TWh[scenarios]=

hydro TWe[scenarios]/TWe per TWh

Units: TWh/Year

Annual electricity generation.

FE Elec generation from NRE TWh[scenarios]=

FE Elec generation from fossil fuels TWh[scenarios]+FE nuclear Elec generation TWh [scenarios]

Units: TWh/Year

Electricity generation from non-renewable resources (fossil fuels and uranium).

FE Elec generation from oceanic TWh[scenarios]=

oceanic TWe[scenarios]/TWe per TWh

Units: TWh/Year

Annual electricity generation.

FE Elec generation from offshore wind TWh[scenarios]=

offshore wind TWe[scenarios]/TWe per TWh

Units: TWh/Year

Annual electricity generation.

FE Elec generation from onshore wind TWh[scenarios]=

onshore wind TWe[scenarios]/TWe per TWh

Units: TWh/Year

Annual electricity generation.

FE Elec generation from solar TWh[scenarios]=

solar TWe[scenarios]/TWe per TWh

Units: TWh/Year

Annual electricity generation.

Grid reinforcement costs[scenarios]=

Grid reinforcement costs ref/(1000*Cp onshore wind)

Units: Tdollars/TWe

Grid reinforcement costs taking as reference the study of Mills et al (2012) for wind:

Grid reinforcement costs ref=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C73')

Units: dollars/kW

Grid reinforcement costs. We take the median from the study of Mills et al (2012) for wind: 300 $/kW.

new onshore wind TWe[scenarios]=

IF THEN ELSE(Time<2014, (Historic onshore wind generation(Time+1)-Historic onshore wind generation (Time))*TWe per TWh, IF THEN ELSE(check electricity[scenarios]<-0.01, "constrain electricity exogenous growth?"[scenarios]*onshore wind TWe[scenarios],

adapt growth onshore wind[scenarios]*onshore wind TWe[scenarios]*Remaining potential onshore wind[scenarios]))

Units: TWe

New annual wind electric power installed (TWe). We use wind as a proxy to estimate the extra investment to cope with variable Elec RES (see Technical Report).

Share variable Elec generation[scenarios]=

IF THEN ELSE((FE Elec generation from NRE TWh[scenarios]+Elec generation variable from RES TWh[scenarios]+"Elec generation base-load from RES TWh"[scenarios])>0, Elec generation variable from RES TWh[scenarios]/(FE Elec generation from NRE TWh[scenarios]+Elec generation variable from RES TWh[scenarios]+"Elec generation base-load from RES TWh"[scenarios]), 0.5)

Units: Dmnl

Share of variable vs. base-load electricity generation. Condition to avoid error when the denominator is zero (0.5 is an arbitrary value).

Share variable vs base load Elec generation delayed 1yr[scenarios]= DELAY FIXED (

Share variable Elec generation[scenarios], 1, 0)

Units: Dmnl

.

TIME STEP = 0.25

Units: Year [0,?]

The time step for the simulation.

15. ELEC RES – Total monetary investments

Cumulated total monet invest RES for Elec[scenarios]= INTEG (

Total monet invest RES for elec Tdolar[scenarios],

0)

Units: Tdollars

Cumulated total monetary investment in RES for electricity generation from 1990.

extra monet invest to cope with variable Elec RES[scenarios]=

(FE Elec generation from onshore wind TWh[scenarios]+FE Elec generation from offshore wind TWh
[scenarios])*Balancing costs

[scenarios]+new onshore wind TWe[scenarios]*Grid reinforcement costs[scenarios
]

Units: Tdollars/Year

Annual additional monetary investment to cope with the

intermittency of RES (taking wind as a proxy) including

balancing and grid reinforcement costs.

GDP[scenarios]=

GDPcap[scenarios]*Population[scenarios]/dollars to Tdollars

Units: Tdollars/Year

Global Domestic Product.

invest bioW Tdolar[scenarios]=

(new BioW TWe[scenarios]+replacement BioW[scenarios])*(Invest cost BioW/Cp BioW
[scenarios])

Units: Tdollars/Year

Investment costs.

"invest geot-elec Tdolar"[scenarios]=

("new geot-elec TWe"[scenarios]+"replacement geot-elec"[scenarios])*("Invest cost geot-elec"
/"Cp geot-elec"[scenarios])

Units: Tdollars/Year

Investment costs.

invest hydro Tdolar[scenarios]=

(new hydro TWe[scenarios]+replacement hydro[scenarios])*(Invest cost hydro
/Cp hydro[scenarios])

Units: Tdollars/Year

Investment costs.

invest oceanic Tdolar[scenarios]=

(new oceanic TWe[scenarios]+replacement oceanic[scenarios])*(Invest cost oceanic
/Cp oceanic[scenarios])

Units: Tdollars/Year

Investment costs.

invest offshore wind Tdolar[scenarios]=

(new offshore wind TWe[scenarios]+replacement offshore wind[scenarios])*(Invest cost offshore wind /Cp offshore wind)

Units: Tdollars/Year

Investment costs.

invest onshore wind Tdolar[scenarios]=

(new onshore wind TWe[scenarios]+replacement onshore wind[scenarios])*(Invest cost onshore wind /Cp onshore wind)

Units: Tdollars/Year

Investment costs.

Invest RES for Elec[scenarios]=

invest bioW Tdolar[scenarios]+"invest geot-elec Tdolar"[scenarios]+invest hydro Tdolar [scenarios]+invest oceanic Tdolar[scenarios]+invest solar Tdolar[scenarios] +invest onshore wind Tdolar[scenarios]+invest offshore wind Tdolar[scenarios]

Units: Tdollars/Year

Annual investment for the installation of RES capacity for electricity .

invest solar Tdolar[scenarios]=

(new solar TWe[scenarios]+replacement solar[scenarios])*(Invest cost solar /Cp solar)

Units: Tdollars/Year

Investment costs.

share extra monet invest to cope with variable Elec RES[scenarios]=

extra monet invest to cope with variable Elec RES[scenarios]/Total monet invest RES for elec Tdolar [scenarios]

Units: **undefined**

Share of the anual additional monetary investment to cope with the intermittency of RES (taking wind as a proxy) in relation to the total investment for RES.

share tot monet invest Elec RES vs GDP[scenarios]=

Total monet invest RES for elec Tdolar[scenarios]/GDP[scenarios]

Units: 1/Year

Annual total monetary investment for RES for electricity as a

share of the annual GDP.

Total monet invest RES for elec Tdolar[scenarios]=

Invest RES for Elec[scenarios]+extra monet invest to cope with variable Elec RES

[scenarios]

Units: Tdollars/Year

Annual total monetary investment for RES for electricity:

capacity, balancing costs and grid improvements to cope with

variability.

16. ELEC – Total FE electricity generation

Abundance electricity[scenarios]=

IF THEN ELSE(Total FE Elec generation TWh[scenarios]>Total FE Elec demand TWh

[scenarios], 1, 1-((Total FE Elec demand TWh[scenarios]-Total FE Elec generation TWh

[scenarios])/Total FE Elec demand TWh[scenarios]))

Units: Dmnl

The parameter abundance varies between (1;0). Abundance=1 while

the supply covers the demand; the closest to 0 indicates a

higher divergence between supply and demand.

check electricity[scenarios]=

(Total FE Elec demand TWh[scenarios]-Total FE Elec generation TWh[scenarios

])/Total FE Elec generation TWh[scenarios]

Units: Dmnl

If=1: demand=supply. If>0: demand>supply. If<0: demand<supply.

Variable to avoid energy oversupply caused by exogenously driven

policies.

"constrain electricity exogenous growth?"[scenarios]=

IF THEN ELSE(check electricity[scenarios]>-0.01 ,1 ,check electricity[scenarios

])

Units: Dmnl

If negative, there is oversupply of electricity. This variable
is used to constrain the exogenous growth of exogenously-driven
policies.

FE Elec generation from coal TWh[scenarios]=
extraction coal without CTL EJ[scenarios]*efficiency coal for electricity*
"share coal/sector for Elec"[scenarios]/EJ per TWh

Units: TWh/Year

Final energy electricity generation from coal (TWh).

FE Elec generation from conv gas TWh[scenarios]=
extraction conv gas without GTL EJ[scenarios]*"share gas/sector for Elec"[
scenarios]*efficiency gas for electricity/EJ per TWh

Units: TWh/Year

Final energy electricity generation from conventional gas (TWh).

FE Elec generation from fossil fuels TWh[scenarios]=
FE Elec generation from coal TWh[scenarios]+FE Elec generation from conv gas TWh
[scenarios]+FE Elec generation from unconv gas TWh[scenarios]+FE Elec generation from total oil TWh
[scenarios]

Units: TWh/Year

Final energy electricity generation from fossil fuels (TWh).

FE Elec generation from NRE TWh[scenarios]=
FE Elec generation from fossil fuels TWh[scenarios]+FE nuclear Elec generation TWh
[scenarios]

Units: TWh/Year

Electricity generation from non-renewable resources (fossil
fuels and uranium).

FE Elec generation from RES TWh[scenarios]=
FE Elec generation from BioW TWh[scenarios]+FE Elec generation from geot TWh
[scenarios]+FE Elec generation from hydro TWh[scenarios]+FE Elec generation from solar TWh
[scenarios]+FE Elec generation from onshore wind TWh[scenarios]+FE Elec generation from offshore wind TWh
[scenarios]+FE Elec generation from oceanic TWh[scenarios]

Units: TWh/Year

Final energy electricity generation from RES (TWh).

FE Elec generation from total oil TWh[scenarios]=

Liquids extraction EJ[scenarios]*"share liquids/sector for Elec"[scenarios

]*efficiency liquids for electricity/EJ per TWh

Units: TWh/Year

Electricity generation (final energy) from total oil.

FE Elec generation from unconv gas TWh[scenarios]=

extraction unconv gas EJ[scenarios]*"share gas/sector for Elec"[scenarios]

*efficiency gas for electricity/EJ per TWh

Units: TWh/Year

Final energy electricity generation from unconventional gas

(TWh).

FE nuclear Elec generation TWh[scenarios]=

extraction uranium EJ[scenarios]*efficiency uranium for electricity/EJ per TWh

Units: TWh/Year

Final energy electricity generation from uranium (TWh).

share RES vs NRE electricity generation[scenarios]=

FE Elec generation from RES TWh[scenarios]/Total FE Elec generation TWh[scenarios

]

Units: Dmnl

Share of RES in the electricity generation.

Total FE Elec demand TWh[scenarios]=

(FE demand Elec consum TWh[scenarios]+increase Elec demand for Transp TWh[

scenarios])*(1+share elec distribution losses)

Units: TWh/Year

Total final energy electricity demand (TWh). It includes new

electric uses (e.g. EV & HEV) and electrical distribution losses.

Total FE Elec generation TWh[scenarios]=

FE Elec generation from NRE TWh[scenarios]+FE Elec generation from RES TWh

[scenarios]

Units: TWh/Year

Total final energy electricity generation (fossil fuels, nuclear
& renewables) (TWh).

Year scarcity Elec[scenarios]=
IF THEN ELSE(Abundance electricity[scenarios]>0.95, 0, Time)

Units: Year

Year when the parameter abundance falls below 0.95, i.e. year
when scarcity starts.

17. RES BIOE – Traditional biomass

MToe per EJ=
GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C6')

Units: MToe/EJ

Unit conversion (1000 Mtoe=41.868 EJ)

PE consumption trad biomass ref=
GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C57')

Units: MToe/Year

Primary energy consumption of ptrad biomass. In 2008, 2.5
billion people consumed 724 Mtoe of traditional biomass (WEO
2010), i.e. 0.29 toe per capita.

PE traditional biomass EJ[scenarios]=
Population[scenarios]*share global pop dependent on trad biomass[scenarios
]*PEpc consumption people depending on trad biomass

Units: EJ/Year

Annual primary energy consumption of traditional biomass.

People relying trad biomass ref=
GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C58')

Units: people

People relying on traditional biomass in 2008. In 2008, 2.5
billion people consumed 724 Mtoe of traditional biomass (WEO
2010), i.e. 0.29 toe per capita.

PEpc consumption people depending on trad biomass=

PE consumption trad biomass ref/(People relying trad biomass ref*MToe per EJ

)

Units: MToe/people

Primary energy per capita consumption of people currently

depending on trad biomass.

Population[scenarios]= INTEG (

pop variation[scenarios],

initial population)

Units: people

Population projection.

Population dependent on trad biomass[scenarios]=

Population[scenarios]*share global pop dependent on trad biomass[scenarios

]

Units: people

Population dependent on traditional biomass.

share global pop dependent on trad biomass[scenarios]=

1-(0.6+(0.85-0.6)/(1+1*EXP(-0.1*(Time dmnl[scenarios](Time)-2030)))^(1/0.8

))

Units: Dmnl

Share of the global population depending on traditional biomass.

We asume that the current consumption ratio is constant over time ("PEpc consumption people depending on trad biomass") together with a reduction in the number of people dependant on traditional biomass from 40% of global population in 2008 to around 25% in 2035 following (WEO, 2010). After 2035 the decreasing trend is maintained, however we introduce a minimum threshold of 15% of the global population dependant on traditional biomass. See Technical Report for more information. [Alternative: linear modeling: IF THEN ELSE(Time<2020, 0.4, MAX(((Time dmnl[scenarios](Time)-2020)/(2035-2020))*(0.25-0.4)+0.4, 0.15))]

Time dmnl[scenarios](

[(1990,1990)-(2100,2100)],(1990,1990),(1991,1991),(1992,1992),(1993,1993),(1994,1994),(1995,1995),(1996,1996),(1997,1997),(1998,1998),(1999,1999),(2000,2000),(2001,2001),(2002,2002),(2003,2003),(2004,2004),(2005,2005),(2006,2006),(2007,2007),(2008,2008),(2009,2009),(2010,2010),(2011,2011),(2012,2012),(2013,2013),(2014,2014),(2015,2015),(2016,2016),(2017,2017),(2018,2018),(2019,2019),(2020,2020),(2021,2021),(2022,2022),(2023,2023),(2024,2024),(2025,2025),(2026,2026),(2027,2027),(2028,2028),(2029,2029),(2030,2030),(2031,2031),(2032,2032),(2033,2033),(2034,2034),(2035,2035),(2036,2036),(2037,2037),(2038,2038),(2039,2039),(2040,2040),(2041,2041),(2042,2042),(2043,2043),(2044,2044),(2045,2045),(2046,2046),(2047,2047),(2048,2048),(2049,2049),(2050,2050),(2051,2051),(2052,2052),(2053,2053),(2054,2054),(2055,2055),(2056,2056),(2057,2057),(2058,2058),(2059,2059),(2060,2060),(2061,2061),(2062,2062),(2063,2063),(2064,2064),(2065,2065),(2066,2066),(2067,2067),(2068,2068),(2069,2069),(2070,2070),(2071,2071),(2072,2072),(2073,2073),(2074,2074),(2075,2075),(2076,2076),(2077,2077),(2078,2078),(2079,2079),(2080,2080),(2081,2081),(2082,2082),(2083,2083),(2084,2084),(2085,2085),(2086,2086),(2087,2087),(2088,2088),(2089,2089),(2090,2090),(2091,2091),(2092,2092),(2093,2093),(2094,2094),(2095,2095),(2096,2096),(2097,2097),(2098,2098),(2099,2099),(2100,2100))

Units: Dmnl

Vector that assigns for every year the number of that same year.

18. RES BIOE – Dedicated crops for biofuels

adapt growth biofuels 2gen[scenarios]=

IF THEN ELSE(Time<2015, 0, IF THEN ELSE(Time<2020, past biofuels 2gen+(P biofuels 2gen [scenarios]-past biofuels 2gen)*(Time dmnl[scenarios](Time)-2015)/5, P biofuels 2gen [scenarios]))

Units: 1/Year

Modeling of a soft transition from current historic annual growth to reach the policy-objective 5 years later. IF THEN ELSE(Time<2015, 0, IF THEN ELSE(Time<2020, past solar+(P solar[scenarios]-past solar)*(Time dmnl[scenarios](Time)-2015)/5, P solar[scenarios]))

Additional land compet available for biofuels[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C41')

Additional land compet available for biofuels[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C41')

Additional land compet available for biofuels[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C41')

Additional land compet available for biofuels[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C41')

Additional land compet available for biofuels[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C41')

Additional land compet available for biofuels[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C41')

Units: MHa/Year

Available land for biofuels in competition with other uses

depending on the scenario.

Additional PE production of bioenergy for biofuels[scenarios]=

PE biomass for biofuels production EJ[scenarios]-Oil liquids saved by biofuels EJ

[scenarios]

Units: EJ/Year

Additional primary energy demand of bioenergy (NPP) for biofuels

in relation to the PEavail. We assume than 1 unit of energy of

biofuels substitutes 1 unit of energy of oil.

Annual additional historic land use biofuels 2gen[scenarios]=

Annual additional historic product biofuels 2gen*EJ per ktoe/Land productivity biofuels 2gen EJ MHa

Units: MHa/Year

Annual additional historic product biofuels 2gen=

IF THEN ELSE(Time<2015, Historic produc biofuels 2gen(Time+1)-Historic produc biofuels 2gen

(Time), 0)

Units: ktoe/Year

Annual additional historic production of liquids from biofuels

ethanol and biodiesel, ktoe/Year (1990-2015). Ref: BP 2016.

Annual shift from 2gen to 3gen[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C44')

Annual shift from 2gen to 3gen[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C44')

Annual shift from 2gen to 3gen[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C44')

Annual shift from 2gen to 3gen[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C44')

Annual shift from 2gen to 3gen[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C44')

Annual shift from 2gen to 3gen[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C44')

Units: 1/Year

Share of the land dedicated for biofuels from the 2nd generation shifted to 3rd generation in the next year.

BioE gen land marg available[scenarios]=

(Max PEavail potential biofuels marginal lands[scenarios]-PEavail biofuels land marg EJ [scenarios])/Max PEavail potential biofuels marginal lands[scenarios]

Units: Dmnl

Remaining potential available as given as a fraction of unity.

BioE potential NPP marginal lands=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C60')

Units: EJ/Year

Potential in marginal lands, i.e. witout competition with current uses. (Field et al., 2008) find that 27 EJ of NPP can be extracted from 386 Mha of marginal lands. We assume that all the production from marginal lands is used for producing liquids.

Biofuels 3gen land compet available[scenarios]=

(Max land compet biofuels 2gen[scenarios]-Land compet biofuels 3gen Mha[scenarios])/Max land compet biofuels 2gen[scenarios]

Units: Dmnl

Remaining potential land available (dedicated to 2nd generation) as given as a fraction of unity. We assume that no new land starts directly to produce biofuels 3rd generation biofuels.

Biofuels land compet available[scenarios]=

(Max land compet biofuels 2gen[scenarios]-Land compet biofuels 2gen Mha[scenarios]-Land compet biofuels 3gen Mha[scenarios])/Max land compet biofuels 2gen[scenarios]

Units: Dmnl

Remaining potential land available as given as a fraction of
unity.

check liquids[scenarios]=
(Total demand liquids EJ[scenarios]-Liquids extraction EJ[scenarios])/Liquids extraction EJ [scenarios]

Units: Dmnl

If=1, demand=supply. If>1, demand>supply. If<0, demand<supply.
Variable to avoid energy oversupply caused by exogenously driven policies.

"constrain liquids exogenous growth?"[scenarios]=
IF THEN ELSE(check liquids[scenarios]>0 ,1 ,check liquids[scenarios])

Units: Dmnl

If negative, there is oversupply of liquids. This variable is used to constrain the exogenous growth of exogenously-driven policies.

Conv efficiency from NPP to biofuels=
GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C61')

Units: Dmnl

Conversion efficiency from net primary productivity (NPP) of biomass to biofuels of 15%. Ref: de Castro & Carpintero (2014).

Efficiency improvement biofuels 3gen=
GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C47')

Units: **undefined**

Efficiency improvements of 3rd generation (cellulosic) in relation to 2nd generation biofuels.

EJ per ktoe=
GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C16')

Units: EJ/ktoe

1 ktoe = 0.000041868 EJ.

EJ per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C5')

Units: EJ/TWh

Unit conversion (3.6 EJ=1000 TWh)

Historic land compet available for biofuels 2gen[scenarios]=

74847.7*EJ per ktoe/Land productivity biofuels 2gen EJ MHa

Units: MHa/Year

Land occupied by biofuels in 2015. Biofuels production in 2015:

7,4847.7 ktoe (BP 2016).

Historic produc biofuels 2gen(

GET XLS LOOKUPS('inputs.xlsx', 'Constants', '25', 'C64'))

Units: ktoe/Year

Historic production of biofuels 2nd generation (1990-2015).

initial value land compet biofuels 2gen Mha=

7096.9*4.1868e-005

Units: EJ/Year

Initial value derived from (BP 2016).

land compet 2gen vs total land compet[scenarios]=

Land compet biofuels 2gen Mha[scenarios]/Land compet required dedicated crops for biofuels

[scenarios]

Units: **undefined**

Land dedicated to 2nd generation biofuels vs total land

competition for biofuels [to prevent stock "Land compet biofuels

2gen Mha" goes negative].

Land compet biofuels 2gen Mha[scenarios]= INTEG (

new biofuels 2gen land compet[scenarios]-Land shifted to biofuels 3gen[scenarios

],

initial value land compet biofuels 2gen Mha*Land productivity biofuels 2gen EJ MHa

)

Units: MHa/Year

Total annual land dedicated to biofuel production in land

competing with other uses.

Land compet biofuels 3gen Mha[scenarios]= INTEG (

Land shifted to biofuels 3gen[scenarios],

0)

Units: MHa/Year

Land subject to competition dedicated to biofuels 3rd generation

as a shift of surface previously dedicated to biofuels from the

2nd generation.

Land compet required dedicated crops for biofuels[scenarios]=

Land compet biofuels 2gen Mha[scenarios]+Land compet biofuels 3gen Mha[scenarios

]

Units: MHa

Land requirements for crops for biofuels 2nd and 3rd generation

(in land competing with other uses).

Land occupation ratio biofuels marg land=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C62')

Units: MHa/EJ

Field et al. (2008) found that 27 EJ of NPP can be extracted

from 386 MHa of marginal lands. So, the land occupation ratio

would be 386 MHa/27 EJ, i.e. 14.3 MHa/EJ NPP.

Land productivity biofuels 2gen EJ MHa=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C59')

Units: EJ/MHa

Energy output per area of biofuels 2nd generation (final

energy). Source: [Mediavilla2013]: 118 Gboe/MHa = 0.047305 EJ/MHa

Land required biofuels land marg[scenarios]=

PEavail biofuels land marg EJ[scenarios]*Land occupation ratio biofuels marg land

/Conv efficiency from NPP to biofuels

Units: MHa/Year

Marginal lands occupied by biofuels.

Land shifted to biofuels 3gen[scenarios]=

IF THEN ELSE(Time<start year 3gen[scenarios],0,IF THEN ELSE(Time<(start year 3gen

[scenarios]+5), Annual shift from 2gen to 3gen[scenarios]*Land compet biofuels 2gen Mha [scenarios]*Biofuels 3gen land compet available[scenarios]*land compet 2gen vs total land compet

[scenarios], P biofuels 3gen[scenarios]*Land compet biofuels 3gen Mha[scenarios

]*Biofuels 3gen land compet available[scenarios]*land compet 2gen vs total land compet

[scenarios]))

Units: **undefined**

New land dedicated to biofuels 3rd generation in land competing

with other uses as a shift of surface previously dedicated to

biofuels from the 2nd generation. We assume that no new land

starts directly to produce biofuels 3rd generation biofuels.

Max land compet biofuels 2gen[scenarios]=

Additional land compet available for biofuels[scenarios]+Historic land compet available for biofuels 2gen

[scenarios]

Units: MHa/Year

Annual potential of biofuels (final energy) 2nd generation

competing with other land uses.

Max PEavail biofuels potential[scenarios]=

Max PEavail potential bioE residues for cellulosic biofuels[scenarios]+"Max PEavail potential biofuels 2-3gen"

[scenarios]+Max PEavail potential biofuels marginal lands[scenarios]

Units: EJ/Year

Maximum biofuels potential (primary energy) available.

Max PEavail potential bioE residues for cellulosic biofuels[scenarios]=

Max NPP potential BioE residues for cellulosic biofuels[scenarios]*Efficiency bioE residues to cellulosic liquids

[scenarios]

Units: **undefined**

"Max PEavail potential biofuels 2-3gen"[scenarios]=

IF THEN ELSE(Time<start year 3gen[scenarios], Max land compet biofuels 2gen

[scenarios]*Land productivity biofuels 2gen EJ MHa, Max land compet biofuels 2gen

[scenarios]*Land productivity biofuels 2gen EJ MHa*(1+Efficiency improvement biofuels 3gen

))

Units: EJ/Year

Annual biofuels potential (primary energy) available from land

competition.

Max PEavail potential biofuels marginal lands[scenarios]=

BioE potential NPP marginal lands*Conv efficiency from NPP to biofuels

Units: EJ/Year

Annual biofuels potential (primary energy) available from

marginal lands

MToe per EJ=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C6')

Units: MToe/EJ

Unit conversion (1000 Mtoe=41.868 EJ)

new biofuels 2gen land compet[scenarios]=

IF THEN ELSE(check liquids[scenarios]<-0.01, "constrain liquids exogenous growth?"

[scenarios]*Land compet biofuels 2gen Mha[scenarios],

MAX(Annual additional historic land use biofuels 2gen[scenarios]+adapt growth biofuels 2gen

[scenarios]

*Land compet biofuels 2gen Mha[scenarios]*Biofuels land compet available[scenarios

],0))

Units: MHa/Year

New land dedicated to biofuels 2nd generation in land competing

with other uses.

new biofuels land marg[scenarios]=

IF THEN ELSE(Time<start year biofuels land marg[scenarios], 0,

IF THEN ELSE(Time<start year biofuels land marg[scenarios]+5, start production biofuels

(Time-start year biofuels land marg[scenarios])*EJ per ktoe,

IF THEN ELSE(check liquids[scenarios]<-0.01, "constrain liquids exogenous growth?"

[scenarios]*PEavail biofuels land marg EJ[scenarios],

adapt growth biofuels 2gen[scenarios]*BioE gen land marg available[scenarios

]*PEavail biofuels land marg EJ[scenarios])))

Units: EJ/Year

New annual production from biofuels in marginal lands. EJ per

ktoe[scenarios]

Oil liquids saved by biofuels EJ[scenarios]=

PEavail total biofuels production EJ[scenarios]

Units: EJ/Year

Oil liquids saved by biofuels.

Oil saved by biofuels MToe[scenarios]=

Oil liquids saved by biofuels EJ[scenarios]*MToe per EJ

Units: MToe/Year

Oil saved by biofuels.

P biofuels 2gen[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C40')

P biofuels 2gen[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C40')

P biofuels 2gen[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C40')

P biofuels 2gen[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C40')

P biofuels 2gen[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C40')

P biofuels 2gen[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C40')

Units: 1/Year

Annual growth in energy output demand depending on the policy of the scenario.

P biofuels 3gen[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C42')

P biofuels 3gen[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C42')

P biofuels 3gen[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C42')

P biofuels 3gen[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C42')

P biofuels 3gen[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C42')

P biofuels 3gen[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C42')

Units: 1/Year

Annual growth in energy output demand depending on the policy of
the scenario.

past biofuels 2gen=
GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C81')
Units: 1/Year
Current growth patterns (1990-2015).

PE biofuels land marg EJ[scenarios]=
PEavail biofuels land marg EJ[scenarios]/Conv efficiency from NPP to biofuels
Units: **undefined**
Total annual primary energy biomass for biofuel production in
marginal lands.

"PE biofuels prod 2gen+3gen EJ"[scenarios]=
(PEavail biofuels prod 3gen EJ[scenarios]+PEavail biofuels 2gen land compet EJ
[scenarios])/Conv efficiency from NPP to biofuels
Units: EJ/Year
Total annual primary energy biomass for biofuel production (2nd
and 3rd generation) in marginal lands.

PE biomass for biofuels production EJ[scenarios]=
PE biofuels land marg EJ[scenarios]+PE cellulosic biofuel EJ[scenarios]+"PE biofuels prod 2gen+3gen EJ"
[scenarios]
Units: EJ/Year
Primary energy of biomass for biofuels production.

PE cellulosic biofuel EJ[scenarios]= INTEG (
new cellulosic biofuels[scenarios],
0)
Units: EJ/Year
Annual primary energy biomass used for cellulosic biofuels.

PEavail biofuels 2gen land compet EJ[scenarios]=
Land compet biofuels 2gen Mha[scenarios]*Land productivity biofuels 2gen EJ MHa
Units: EJ/Year
Primary energy available of biofuels from dedicated crops (2nd

generation).

PEavail biofuels land marg EJ[scenarios]= INTEG (
new biofuels land marg[scenarios],
0)
Units: EJ/Year
Total annual biofuel production in marginal lands.

PEavail biofuels prod 3gen EJ[scenarios]=
Land compet biofuels 3gen Mha[scenarios]*Land productivity biofuels 2gen EJ MHa
*(1+Efficiency improvement biofuels 3gen)
Units: EJ/Year
Final Energy production (EJ) of biofuels from dedicated crops
(3rd generation).

PEavail cellulosic biofuel EJ[scenarios]=
PE cellulosic biofuel EJ[scenarios]*Efficiency bioE residues to cellulosic liquids
[scenarios]
Units: EJ/Year
Cellulosic biofuels production from bioenergy-residues.

PEavail total biofuels production EJ[scenarios]=
PEavail biofuels 2gen land compet EJ[scenarios]+PEavail biofuels land marg EJ
[scenarios]+PEavail biofuels prod 3gen EJ[scenarios]+PEavail cellulosic biofuel EJ
[scenarios]
Units: EJ/Year
Final energy total biofuels production.

PEavail total biofuels production TWe[scenarios]=
PEavail total biofuels production EJ[scenarios]*TWe per TWh/EJ per TWh
Units: TWe
Final energy total biofuels production (2nd & 3rd generation).

start production biofuels=
GET XLS LOOKUPS('inputs.xlsx', 'Parameters', '28', 'B29')
Units: ktoe/Year
Exogenous start production scenario from the year "start year

biofuels land marg". It mimics the biofuel 2nd generation
deployment from the year 2000.

start year 3gen[BAU]=
GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C43')
start year 3gen[SCEN1]=
GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C43')
start year 3gen[SCEN2]=
GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C43')
start year 3gen[SCEN3]=
GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C43')
start year 3gen[SCEN4]=
GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C43')
start year 3gen[User defined]=
GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C43')
Units: Year
First year when 3rd generation biofuels are available.

start year biofuels land marg[BAU]=
GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C45')
start year biofuels land marg[SCEN1]=
GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C45')
start year biofuels land marg[SCEN2]=
GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C45')
start year biofuels land marg[SCEN3]=
GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C45')
start year biofuels land marg[SCEN4]=
GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C45')
start year biofuels land marg[User defined]=
GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C45')
Units: Year
First year when the technology "biofuels land marg" is available.

Time dmnl[scenarios](
[(1990,1990)-(2100,2100)],(1990,1990),(1991,1991),(1992,1992),(1993,1993),
(1994,1994),(1995,1995),(1996,1996),(1997,1997),(1998,1998),(1999,1999),(2000
,2000),(2001,2001),(2002,2002),(2003,2003),(2004,2004),(2005,2005),(2006,2006

),(2007,2007),(2008,2008),(2009,2009),(2010,2010),(2011,2011),(2012,2012),(
2013,2013),(2014,2014),(2015,2015),(2016,2016),(2017,2017),(2018,2018),(2019
,2019),(2020,2020),(2021,2021),(2022,2022),(2023,2023),(2024,2024),(2025,2025
),(2026,2026),(2027,2027),(2028,2028),(2029,2029),(2030,2030),(2031,2031),(
2032,2032),(2033,2033),(2034,2034),(2035,2035),(2036,2036),(2037,2037),(2038
,2038),(2039,2039),(2040,2040),(2041,2041),(2042,2042),(2043,2043),(2044,2044
),(2045,2045),(2046,2046),(2047,2047),(2048,2048),(2049,2049),(2050,2050),(
2051,2051),(2052,2052),(2053,2053),(2054,2054),(2055,2055),(2056,2056),(2057
,2057),(2058,2058),(2059,2059),(2060,2060),(2061,2061),(2062,2062),(2063,2063
),(2064,2064),(2065,2065),(2066,2066),(2067,2067),(2068,2068),(2069,2069),(
2070,2070),(2071,2071),(2072,2072),(2073,2073),(2074,2074),(2075,2075),(2076
,2076),(2077,2077),(2078,2078),(2079,2079),(2080,2080),(2081,2081),(2082,2082
),(2083,2083),(2084,2084),(2085,2085),(2086,2086),(2087,2087),(2088,2088),(
2089,2089),(2090,2090),(2091,2091),(2092,2092),(2093,2093),(2094,2094),(2095
,2095),(2096,2096),(2097,2097),(2098,2098),(2099,2099),(2100,2100))

Units: Dmnl

Vector that assigns for every year the number of that same year.

TWe per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C7')

Units: TWe/(TWh/Year)

Unit conversion (1 TWe=8760 TWh per year)

19. RES BIOE – Crop and forest residues

"BioE residues for heat+elec available"[scenarios]=

(Max NPP potential BioE residues for heat and elec[scenarios]-"PE BioE residues for heat+elec EJ"[scenarios])/Max NPP potential BioE residues for heat and elec[scenarios]

Units: Dmnl

Remaining potential available of bioenergy residues for heat and electricity as given as a fraction of unity.

Cellulosic biofuels available[scenarios]=

(Max NPP potential BioE residues for cellulosic biofuels[scenarios]-PE cellulosic biofuel EJ[scenarios])/Max NPP potential BioE residues for cellulosic biofuels[scenarios
]

Units: Dmnl

Remaining potential available as given as a fraction of unity.

check liquids[scenarios]=

(Total demand liquids EJ[scenarios]-Liquids extraction EJ[scenarios])/Liquids extraction EJ [scenarios]

Units: Dmnl

If=1, demand=supply. If>1, demand>supply. If<0, demand<supply.

Variable to avoid energy oversupply caused by exogenously driven policies.

"constrain liquids exogenous growth?"[scenarios]=

IF THEN ELSE(check liquids[scenarios]>0 ,1 ,check liquids[scenarios])

Units: Dmnl

If negative, there is oversupply of liquids. This variable is used to constrain the exogenous growth of exogenously-driven policies.

Conv efficiency from NPP to biofuels=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C61')

Units: Dmnl

Conversion efficiency from net primary productivity (NPP) of biomass to biofuels of 15%. Ref: de Castro & Carpintero (2014).

Efficiency bioE residues to cellulosic liquids[scenarios]=

Conv efficiency from NPP to biofuels

Units: Dmnl

Efficiency of the transformation from bioenergy residues to cellulosic liquids. We assume it is the same efficiency than for the conversion from biomass to 2nd generation biofuels.

efficiency conversion bioE residues to Elec=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C44')

Units: Dmnl

Efficiency of the transformation from bioenergy to electricity (de Castro & Carpintero et al (2014) cite 10-30% range.

Efficiency conversion BioE residues to heat=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C43')

Units: Dmnl

Efficiency of the transformation from bioenergy to heat.

EJ per ktoe=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C16')

Units: EJ/ktoe

1 ktoe = 0.000041868 EJ.

Elec potential from BioE residues EJ[scenarios]=

PE bioE residues for Elec EJ[scenarios]*efficiency conversion bioE residues to Elec

Units: EJ/Year

Electricity potential from bioenergy-residues.

Heat potential from Bio residues EJ[scenarios]=

PE bioE residues for heat EJ[scenarios]*Efficiency conversion BioE residues to heat

Units: EJ/Year

Thermal energy potential from bioenergy-residues.

Max NPP potential bioE residues[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C55')

Max NPP potential bioE residues[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C55')

Max NPP potential bioE residues[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C55')

Max NPP potential bioE residues[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C55')

Max NPP potential bioE residues[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C55')

Max NPP potential bioE residues[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C55')

Units: EJ/Year

Potencial following WBGU (2009).

Max NPP potential BioE residues for cellulosic biofuels[scenarios]=

Max NPP potential bioE residues[User defined]*share cellulosic biofuels vs BioE residues

[scenarios]

Units: EJ/Year

Potential assigned to the cellulosic biofuels from bioE residues.

Max NPP potential BioE residues for heat[scenarios]=

Max NPP potential BioE residues for heat and elec[scenarios]*"share bioE residues for heat vs heat+elec"

[scenarios]

Units: EJ/Year

Sustainable potential NPP residues for bioenergy for heat.

Max NPP potential BioE residues for heat and elec[scenarios]=

Max NPP potential bioE residues[User defined]*(1-share cellulosic biofuels vs BioE residues

[scenarios])

Units: EJ/Year

Share of bioE for heat and electricity.

Max PEavail potential bioE residues for cellulosic biofuels[scenarios]=

Max NPP potential BioE residues for cellulosic biofuels[scenarios]*Efficiency bioE residues to cellulosic liquids

[scenarios]

Units: **undefined**

"new BioE residues for heat+elec"[scenarios]=

IF THEN ELSE(Time<"start year BioE residues for heat+elec"[scenarios], 0,

IF THEN ELSE(Time<"start year BioE residues for heat+elec"

[scenarios]+5, start production biofuels(Time-"start year BioE residues for heat+elec"

[scenarios])*EJ per ktoe,

"P bioE residues for heat+elec"[scenarios]*"PE BioE residues for heat+elec EJ"

[scenarios]*"BioE residues for heat+elec available"[scenarios]))

Units: EJ/(Year*Year)

BioE residues used for heat and electricity.

new cellulosic biofuels[scenarios]=

IF THEN ELSE(Time<start year cellulosic biofuels[scenarios], 0,

IF THEN ELSE(Time<start year cellulosic biofuels[scenarios]+5, start production biofuels

(Time-start year cellulosic biofuels[scenarios])*EJ per ktoe,

IF THEN ELSE(check liquids[scenarios]<-0.01, "constrain liquids exogenous growth?"

[scenarios]*PE cellulosic biofuel EJ[scenarios],

P cellulosic biofuels[scenarios]*PE cellulosic biofuel EJ[scenarios]*Cellulosic biofuels available [scenarios])))

Units: EJ/Year

New annual production of cellulosic biofuels from bioE residues.

"P bioE residues for heat+elec"[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C46')

"P bioE residues for heat+elec"[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C46')

"P bioE residues for heat+elec"[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C46')

"P bioE residues for heat+elec"[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C46')

"P bioE residues for heat+elec"[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C46')

"P bioE residues for heat+elec"[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C46')

Units: 1/Year

Annual growth in energy output demand depending on the policy of the scenario.

P cellulosic biofuels[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C49')

P cellulosic biofuels[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C49')

P cellulosic biofuels[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C49')

P cellulosic biofuels[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C49')

P cellulosic biofuels[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C49')

P cellulosic biofuels[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C49')

Units: 1/Year

Annual growth in energy output demand depending on the policy of the scenario.

PE bioE residues for Elec EJ[scenarios]=

"PE BioE residues for heat+elec EJ"[scenarios]*(1-"share bioE residues for heat vs heat+elec"
[scenarios])
Units: EJ/Year

PE bioE residues for heat EJ[scenarios]=
"PE BioE residues for heat+elec EJ"[scenarios]*"share bioE residues for heat vs heat+elec"
[scenarios]
Units: EJ/Year

"PE BioE residues for heat+elec EJ"[scenarios]= INTEG (
"new BioE residues for heat+elec"[scenarios],
0)
Units: EJ/Year
Total annual bioE residues production.

PE cellulosic biofuel EJ[scenarios]= INTEG (
new cellulosic biofuels[scenarios],
0)
Units: EJ/Year
Annual primary energy biomass used for cellulosic biofuels.

PEavail cellulosic biofuel EJ[scenarios]=
PE cellulosic biofuel EJ[scenarios]*Efficiency bioE residues to cellulosic liquids
[scenarios]
Units: EJ/Year
Cellulosic biofuels production from bioenergy-residues.

"share bioE residues for heat vs heat+elec"[BAU]=
GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C48')
"share bioE residues for heat vs heat+elec"[SCEN1]=
GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C48')
"share bioE residues for heat vs heat+elec"[SCEN2]=
GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C48')
"share bioE residues for heat vs heat+elec"[SCEN3]=
GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C48')
"share bioE residues for heat vs heat+elec"[SCEN4]=
GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C48')

"share bioE residues for heat vs heat+elec"[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C48')

Units: Dmnl

Share of the BioE residues for heat vs. heat+electricity.

Agricultural and forestry uses will be assumed to be mostly used in thermal applications (75%), as it currently happens (IPCC, 2007a, 2007b).

share cellulosic biofuels vs BioE residues[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C51')

share cellulosic biofuels vs BioE residues[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C51')

share cellulosic biofuels vs BioE residues[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C51')

share cellulosic biofuels vs BioE residues[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C51')

share cellulosic biofuels vs BioE residues[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C51')

share cellulosic biofuels vs BioE residues[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C51')

Units: Dmnl

Share bioenergy residues potential allocated to cellulosic biofuels production.

start production biofuels=

GET XLS LOOKUPS('inputs.xlsx', 'Parameters', '28', 'B29')

Units: ktoe/Year

Exogenous start production scenario from the year "start year biofuels land marg". It mimics the biofuel 2nd generation deployment from the year 2000.

"start year BioE residues for heat+elec"[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C47')

"start year BioE residues for heat+elec"[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C47')

"start year BioE residues for heat+elec"[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C47')

"start year BioE residues for heat+elec"[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C47')

"start year BioE residues for heat+elec"[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C47')

"start year BioE residues for heat+elec"[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C47')

Units: Year

First year when the technology is available.

start year cellulosic biofuels[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C50')

start year cellulosic biofuels[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C50')

start year cellulosic biofuels[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C50')

start year cellulosic biofuels[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C50')

start year cellulosic biofuels[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C50')

start year cellulosic biofuels[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C50')

Units: Year

First year when the technology is available.

20. RES HEAT

abundance thermal RES[scenarios]=

SQRT(ABS((PE demand for IB after RES EJ[scenarios]-thermal RES supply[scenarios

])/PE demand for IB after RES EJ[scenarios]))

Units: **undefined**

adapt growth thermal RES for Build[scenarios]=

IF THEN ELSE(Time<2012, past thermal RES for Build, IF THEN ELSE(Time<2017

, past thermal RES for Build+(P thermal RES for Build

[scenarios]-past thermal RES for Build)*(Time dmnl[scenarios](Time)-2012)/

5, P thermal RES for Build[scenarios])*abundance thermal RES[scenarios])

Units: 1/Year

Modeling of a soft transition from current historic annual

growth to reach the policy-objective 5 years later.

adapt growth thermal RES for Ind[scenarios]=

IF THEN ELSE(Time<2015, past thermal RES for Ind, IF THEN ELSE(Time<2020,

past thermal RES for Ind+(P thermal RES for Ind

[scenarios]-past thermal RES for Ind)*(Time dmnl[scenarios](Time)-2015)/5,

P thermal RES for Ind[scenarios])*abundance thermal RES[scenarios])

Units: 1/Year

Modeling of a soft transition from current historic annual

growth to reach the policy-objective 5 years later.

check IB[scenarios]=

(PE demand for IB after RES EJ[scenarios]-PES for IB EJ[scenarios])/PES for IB EJ

[scenarios]

Units: Dmnl

If=1: demand=supply. If>0: demand>supply. If<0: demand<supply.

Variable to avoid energy oversupply caused by exogenously driven

policies.

"constrain IB exogenous growth?"[scenarios]=

IF THEN ELSE(check IB[scenarios]>-0.05 ,1 ,check IB[scenarios])

Units: Dmnl

If negative, there is oversupply of energy in the IB sector.

This variable is used to constrain the exogenous growth of

exogenously-driven policies. We use the value 0.05 instead of 0

to help to converge the model.

Cp baseload reduction[scenarios]=

MIN(1,-0.6209*(Share variable vs base load Elec generation delayed 1yr[scenarios

])^2 - 0.3998*(Share variable vs base load Elec generation delayed 1yr[scenarios

]) + 1.0222)

Units: Dmnl

Reduction of the capacity factor of the baseload plants as a

function of the penetration of variables RES in the electricity

generation.

EJ per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C5')

Units: EJ/TWh

Unit conversion (3.6 EJ=1000 TWh)

Geothermal PE potential TWth[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C56')

Geothermal PE potential TWth[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C56')

Geothermal PE potential TWth[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C56')

Geothermal PE potential TWth[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C56')

Geothermal PE potential TWth[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C56')

Geothermal PE potential TWth[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C56')

Units: TWth

Geothermal primary energy potential.

Geothermal PE thermal potential[scenarios]=

Geothermal PE potential TWth[scenarios]*(1-share geot for elec[scenarios])

*EJ per TWh/TWe per TWh

Units: EJ/Year

Geothermal thermal potential (primary energy).

Historic RES thermal for Build(

GET XLS LOOKUPS('inputs.xlsx', 'Constants', '25', 'C67'))

Units: EJ/Year

Annual historic primary energy of RES in Buildings sector

(1990-2007). Ref: WoLiM 1.0 & IEOs (see Technical Report).

Historic RES thermal for Ind(

GET XLS LOOKUPS('inputs.xlsx', 'Constants', '25', 'C66'))

Units: EJ/Year

Annual historic primary energy of RES in Industrial sector

(1990-2007). Ref: WoLiM 1.0 & IEOs (see Technical Report).

initial value thermal RES for Build=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C67')

Units: EJ/Year

Thermal RES supply in the Industry sector in the year 1990.

initial value thermal RES for Ind=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C66')

Units: EJ/Year

Thermal RES supply in the Industry sector in the year 1990.

life time RES thermal Build=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C65')

Units: Year

Lifetime RES thermal technologies and plants in the Industry sector.

life time RES thermal Ind=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C64')

Units: Year

Lifetime RES thermal technologies and plants in the Industry sector.

Max NPP potential BioE residues for heat[scenarios]=

Max NPP potential BioE residues for heat and elec[scenarios]*"share bioE residues for heat vs heat+elec"[scenarios]

Units: EJ/Year

Sustainable potential NPP residues for bioenergy for heat.

Max potential NPP thermal BioE conventional[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C54')

Max potential NPP thermal BioE conventional[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C54')

Max potential NPP thermal BioE conventional[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C54')

Max potential NPP thermal BioE conventional[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C54')

Max potential NPP thermal BioE conventional[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C54')

Max potential NPP thermal BioE conventional[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C54')

Units: EJ/Year

Sustainable potential NPP of conventional bioenergy for heat.

Source: Technical Report.

Max potential PE thermal RES[scenarios]=

Max NPP potential BioE residues for heat[scenarios]+Max potential NPP thermal BioE conventional [User defined]+Geothermal PE thermal potential[scenarios]+Solar thermal potential [scenarios]

Units: EJ/Year

Maximum potential thermal RES without traditional biomass.

New thermal RES supply for Build[scenarios]=

IF THEN ELSE(Time<2006, Historic RES thermal for Build(Time+1)-Historic RES thermal for Build (Time),

IF THEN ELSE(check IB[scenarios]<-0.05, "constrain IB exogenous growth?"[scenarios]*thermal RES supply for Build[scenarios],

adapt growth thermal RES for Build[scenarios]*thermal RES supply for Build [scenarios]*remaining potential thermal RES[scenarios]))

Units: EJ/Year

New thermal RES supply for Buildings.

New thermal RES supply for Ind[scenarios]=

IF THEN ELSE(Time<2006, Historic RES thermal for Ind(Time+1)-Historic RES thermal for Ind (Time),

IF THEN ELSE(check IB[scenarios]<-0.05, "constrain IB exogenous growth?"[scenarios]*thermal RES supply for Ind[scenarios],

adapt growth thermal RES for Ind[scenarios]*thermal RES supply for Ind[scenarios]*remaining potential thermal RES[scenarios]))

Units: EJ/Year

New thermal RES supply for Industry.

P thermal RES for Build[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C59')

P thermal RES for Build[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C59')

P thermal RES for Build[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C59')

P thermal RES for Build[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C59')

P thermal RES for Build[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C59')

P thermal RES for Build[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C59')

Units: 1/Year

Annual growth in RES thermal supply in the Buildings sector

depending on the policy of the scenario.

P thermal RES for Ind[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C58')

P thermal RES for Ind[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C58')

P thermal RES for Ind[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C58')

P thermal RES for Ind[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C58')

P thermal RES for Ind[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C58')

P thermal RES for Ind[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C58')

Units: 1/Year

Annual growth in RES thermal supply in the Industry sector

depending on the policy of the scenario.

past thermal RES for Build=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C92')

Units: 1/Year

Historic annual average growth (1990-2014).

past thermal RES for Ind=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C91')

Units: 1/Year

Historic annual average growth (1990-2014).

PE demand for IB after RES EJ[scenarios]=

"PE demand Ind after RES+efficiency EJ"[scenarios]+"PE demand Build after RES+efficiency EJ"
[scenarios]

Units: EJ/Year

Primary energy demand for Industry and Buildings sector after
policies.

PE supply thermal RES for Build[scenarios]=

thermal RES supply for Build[scenarios]

Units: EJ

Primary energy supply of thermal RES for sector Buildings.

PE supply thermal RES for Indus[scenarios]=

thermal RES supply for Ind[scenarios]

Units: EJ

Primary energy supply of thermal RES for sector Industry.

remaining potential thermal RES[scenarios]=

(Max potential PE thermal RES[scenarios]-thermal RES supply[scenarios])/Max potential PE thermal RES
[scenarios]

Units: Dmnl

Remaining potential available as given as a fraction of unity.

replacement rate thermal RES for Build=

1

Units: Dmnl

If =1, we asume that all the power that reaches the end of its
lifetime is replaced.

replacement rate thermal RES for Ind=

1

Units: Dmnl

If =1, we asume that all the power that reaches the end of its
lifetime is replaced.

replacement thermal RES for Build[scenarios]=

wear thermal RES for Build[scenarios]*replacement rate thermal RES for Build

Units: EJ

If replacement rate=1, we asume that all the power that reaches

the end of its lifetime is replaced.

replacement thermal RES for Ind[scenarios]=

wear thermal RES for Ind[scenarios]*replacement rate thermal RES for Ind

Units: EJ

If replacement rate=1, we asume that all the power that reaches

the end of its lifetime is replaced.

share geot for elec[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C25')

share geot for elec[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C25')

share geot for elec[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C25')

share geot for elec[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C25')

share geot for elec[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C25')

share geot for elec[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C25')

Units: TWe

Share of geothermal for electricity in relation to the total

potential of geothermal (including thermal uses).

Solar thermal potential[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C53')

Solar thermal potential[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C53')

Solar thermal potential[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C53')

Solar thermal potential[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C53')

Solar thermal potential[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C53')

Solar thermal potential[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C53')

Units: EJ/Year

Global solar thermal potential. We assume that the primary energy coincides with the final energy. See Technical Report Appendix D.

thermal RES supply[scenarios]=

thermal RES supply for Ind[scenarios]+thermal RES supply for Build[scenarios
]

Units: EJ

Total thermal RES supply (Industry + Buildings).

thermal RES supply for Build[scenarios]= INTEG (

New thermal RES supply for Build[scenarios]+replacement thermal RES for Build
[scenarios]-wear thermal RES for Build[scenarios],

initial value thermal RES for Build)

Units: EJ

Annual thermal RES supply for Buildings.

thermal RES supply for Ind[scenarios]= INTEG (

New thermal RES supply for Ind[scenarios]+replacement thermal RES for Ind[
scenarios]-wear thermal RES for Ind[scenarios],

initial value thermal RES for Ind)

Units: EJ

Annual thermal RES supply for Industry.

Time dmnl[scenarios](

[(1990,1990)-(2100,2100)],(1990,1990),(1991,1991),(1992,1992),(1993,1993),
(1994,1994),(1995,1995),(1996,1996),(1997,1997),(1998,1998),(1999,1999),(2000
,2000),(2001,2001),(2002,2002),(2003,2003),(2004,2004),(2005,2005),(2006,2006
),(2007,2007),(2008,2008),(2009,2009),(2010,2010),(2011,2011),(2012,2012),(
2013,2013),(2014,2014),(2015,2015),(2016,2016),(2017,2017),(2018,2018),(2019
,2019),(2020,2020),(2021,2021),(2022,2022),(2023,2023),(2024,2024),(2025,2025
),(2026,2026),(2027,2027),(2028,2028),(2029,2029),(2030,2030),(2031,2031),(

2032,2032),(2033,2033),(2034,2034),(2035,2035),(2036,2036),(2037,2037),(2038
,2038),(2039,2039),(2040,2040),(2041,2041),(2042,2042),(2043,2043),(2044,2044
),(2045,2045),(2046,2046),(2047,2047),(2048,2048),(2049,2049),(2050,2050),(
2051,2051),(2052,2052),(2053,2053),(2054,2054),(2055,2055),(2056,2056),(2057
,2057),(2058,2058),(2059,2059),(2060,2060),(2061,2061),(2062,2062),(2063,2063
),(2064,2064),(2065,2065),(2066,2066),(2067,2067),(2068,2068),(2069,2069),(
2070,2070),(2071,2071),(2072,2072),(2073,2073),(2074,2074),(2075,2075),(2076
,2076),(2077,2077),(2078,2078),(2079,2079),(2080,2080),(2081,2081),(2082,2082
),(2083,2083),(2084,2084),(2085,2085),(2086,2086),(2087,2087),(2088,2088),(
2089,2089),(2090,2090),(2091,2091),(2092,2092),(2093,2093),(2094,2094),(2095
,2095),(2096,2096),(2097,2097),(2098,2098),(2099,2099),(2100,2100))

Units: Dmnl

Vector that assigns for every year the number of that same year.

TWe per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C7')

Units: TWe/(TWh/Year)

Unit conversion (1 TWe=8760 TWh per year)

wear thermal RES for Build[scenarios]=

thermal RES supply for Build[scenarios]/life time RES thermal Build

Units: EJ

Decommission of the capacity that reachs the end of its lifetime.

wear thermal RES for Ind[scenarios]=

thermal RES supply for Ind[scenarios]/life time RES thermal Ind

Units: EJ

Decommission of the capacity that reachs the end of its lifetime.

21. RES – PED from non-electric RES

Max PEavail biofuels potential[scenarios]=

Max PEavail potential bioE residues for cellulosic biofuels[scenarios]+"Max PEavail potential biofuels 2-3gen"

[scenarios]+Max PEavail potential biofuels marginal lands[scenarios]

Units: EJ/Year

Maximum biofuels potential (primary energy) available.

"Max potential PE non-electric RES"[scenarios]=

Max potential PE thermal RES[scenarios]+Max PEavail biofuels potential[scenarios

]

Units: EJ/Year

Techno-ecological sustainable potential (primary energy) of

non-electric RES.

Max potential PE thermal RES[scenarios]=

Max NPP potential BioE residues for heat[scenarios]+Max potential NPP thermal BioE conventional

[User defined]+Geothermal PE thermal potential[scenarios]+Solar thermal potential

[scenarios]

Units: EJ/Year

Maximum potential thermal RES without traditional biomass.

Oil liquids saved by biofuels EJ[scenarios]=

PEavail total biofuels production EJ[scenarios]

Units: EJ/Year

Oil liquids saved by biofuels.

PE biomass for biofuels production EJ[scenarios]=

PE biofuels land marg EJ[scenarios]+PE cellulosic biofuel EJ[scenarios]+"PE biofuels prod 2gen+3gen EJ"

[scenarios]

Units: EJ/Year

Primary energy of biomass for biofuels production.

"PE supply from RES non-elec without trad bioE EJ"[scenarios]=

PE supply thermal RES for Indus[scenarios]+PE supply thermal RES for Build

[scenarios]+PEavail total biofuels production EJ

[scenarios]

Units: EJ/Year

Primary energy (non electric) supply from RES without

traditional biomass.

"PE supply RES non-Elec EJ"[scenarios]=

"PE supply from RES non-elec without trad bioE EJ"[scenarios]+PE traditional biomass EJ

[scenarios]

Units: EJ/Year

Primary energy (non electricity) from RES, including traditional

biomass.

PE supply thermal RES for Build[scenarios]=

thermal RES supply for Build[scenarios]

Units: EJ

Primary energy supply of thermal RES for sector Buildings.

PE supply thermal RES for Indus[scenarios]=

thermal RES supply for Ind[scenarios]

Units: EJ

Primary energy supply of thermal RES for sector Industry.

PE traditional biomass EJ[scenarios]=

Population[scenarios]*share global pop dependent on trad biomass[scenarios

]*PEpc consumption people depending on trad biomass

Units: EJ/Year

Annual primary energy consumption of traditional biomass.

PEavail total biofuels production EJ[scenarios]=

PEavail biofuels 2gen land compet EJ[scenarios]+PEavail biofuels land marg EJ

[scenarios]+PEavail biofuels prod 3gen EJ[scenarios]+PEavail cellulosic biofuel EJ

[scenarios]

Units: EJ/Year

Final energy total biofuels production.

22. RES – TPE extraction

MToe per EJ=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C6')

Units: MToe/EJ

Unit conversion (1000 Mtoe=41.868 EJ)

PE Elec generation from RES EJ[scenarios]=

PE BioW for Elec generation EJ[scenarios]+(PE geot for Elec generation EJ[

scenarios]+PE hydro for Elec generation EJ

[scenarios]+PE oceanic for Elec generation EJ[scenarios]+PE solar for Elec generation EJ
[scenarios]+PE onshore wind for Elec generation EJ
[scenarios]+PE offshore wind for Elec generation EJ[scenarios])/RES to fossil accounting
[scenarios]

Units: EJ/Year

Primary energy from RES electricity generation. For all sources
excepting "Bio" the factor "RES to fossil accounting" is applied
for the equivalent primary energy.

"PE supply RES non-Elec EJ"[scenarios]=
"PE supply from RES non-elec without trad bioE EJ"[scenarios]+PE traditional biomass EJ
[scenarios]

Units: EJ/Year

Primary energy (non electricity) from RES, including traditional
biomass.

share RES for Elec vs TPE RES[scenarios]=
PE Elec generation from RES EJ[scenarios]/("PE supply RES non-Elec EJ"[scenarios
]+PE Elec generation from RES EJ[scenarios])

Units: Dmnl

Share of RES for electricity in relation to TPE RES.

TPE from RES EJ[scenarios]=
PE Elec generation from RES EJ[scenarios]+"PE supply RES non-Elec EJ"[scenarios
]

Units: EJ/Year

Total primary energy supply from all RES.

TPE from RES Mtoe[scenarios]=
TPE from RES EJ[scenarios]*MToe per EJ

Units: MToe/Year

Total primary energy supply from all RES.

23. TRANSP – Transport energy demand

"'a' historical I-TRANSP":INTERPOLATE::=
GET XLS DATA('inputs.xlsx', 'Constants', '25', 'C31')

Units: Dmnl

Historical annual primary energy intensity improvement of the Transportation sector, "a" parameter in 1971-2007: a=I(t)/I(t-1).

"a I-TRANSP projection"[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C12')

"a I-TRANSP projection"[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C12')

"a I-TRANSP projection"[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C12')

"a I-TRANSP projection"[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C12')

"a I-TRANSP projection"[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C12')

"a I-TRANSP projection"[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C12')

Units: Dmnl

Evolution depending on the scenario of the "a" parameter, which represents the annual PE intensity improvement of the sector, i.e. indirectly the Annual Efficiency Improvements (a=1-AEI), Constant value over time.

"Adapt 'a' I-TRANSP"[scenarios]=

IF THEN ELSE(Time>2015,IF THEN ELSE(Time<"year 'a-TRANSP' projected reached"[scenarios],"'a' historical I-TRANSP"+("a I-TRANSP projection"[scenarios]-"'a' historical I-TRANSP")*(Time-2016)/("year 'a-TRANSP' projected reached"[scenarios]-2016), "a I-TRANSP projection"[scenarios]),"'a' historical I-TRANSP")

Units: Dmnl

Smoothing transition for the parameter "a" between the historical trends and the projected trend. The projected trend is reached at "year 'a-sector' projected reached".

current trends demand Elec for Transp[scenarios]=

PE demand for Transport initial EJ[scenarios]*Current trends electric transport share [scenarios]

Units: EJ/Year

Current trends of Demand of electricity for Transportation (EJ).

We assume that the share of current TPE demand of transport covered by electricity (excepting alternative policies) is maintained constant in the future. Since we extrapolate the current trends, the electricity consumption is not increased assuming that current trends are already included in the electricity consumption trend.

demand gas for Transp EJ[scenarios]=

PE demand for Transport initial EJ[scenarios]*propor gas transp losses+Oil liquids saved by NGVs [scenarios]

Units: EJ/Year

Energy demand in form of gas of Transportation.

GDP[scenarios]=

GDPcap[scenarios]*Population[scenarios]/dollars to Tdollars

Units: Tdollars/Year

Global Domestic Product.

GDP delayed 1yr[scenarios]= DELAY FIXED (

GDP[scenarios], 1, 39.435)

Units: Tdollars/Year

GDP projection delayed 1 year. Data from World Bank -->

GDP(1989)=39.435 T$ US2011. .

"I-TRANSP delayed 1yr"[scenarios]=

PE demand for Transport initial EJ delayed 1yr[scenarios]/GDP delayed 1yr[scenarios]

Units: EJ/Tdollars

Energy intensity of the Transportation sector delayed 1 year.

"I-TRANSP min"[scenarios]=

"I-TRANSP(1990)"*pct Imin[scenarios]

Units: EJ/Tdollars

Horizontal asymptote that represents the minimum value of the future primary energy intensity of the Transportation sector (following Schenk and Moll, 2007 equation).

"I-TRANSP"[scenarios]=

IF THEN ELSE(Time>2015 ,"I-TRANSP min"[scenarios]+("I-TRANSP(t=0), i.e. 2015" -"I-TRANSP min"[scenarios])*"Adapt 'a' I-TRANSP"[scenarios]^"t I-TRANSP"[scenarios],"'a' historical I-TRANSP"*"I-TRANSP delayed 1yr"[scenarios])

Units: EJ/Tdollars

Primary energy consumption intensity of the Transportation sector. Equation as a physical indicator as proposed by (Schenk and Moll, 2007) I_t=I_min+(I_(t=0)-I_min)·a^t

"I-TRANSP(1990)"=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C105')

Units: EJ/Tdollars

Value of the primary energy intensity of the Transport sector in 1990.

"I-TRANSP(t=0), i.e. 2015"=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C102')

Units: EJ/Tdollars

Value of the primary energy intensity of the Transportation sector in the initial year (2015) to apply Schenk and Moll, 2007 equation.

Liquid demand transp initial EJ[scenarios]=

PE demand for Transport initial EJ[scenarios]*(1-propor gas transp losses) -current trends demand Elec for Transp[scenarios]

Units: EJ/Year

Demand of liquids by the Transportation sector.

MToe per EJ=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C6')

Units: MToe/EJ

Unit conversion (1000 Mtoe=41.868 EJ)

Oil liquids saved by EVs EJ[scenarios]=

Liquid demand transp initial EJ[scenarios]*(BEV share[scenarios]+(1/3)*HEV share [scenarios])

Units: EJ/Year

Oil liquids saved by electric vehicles (BEV and HEV).

Oil liquids saved by NGVs[scenarios]=

NGV share[scenarios]*Liquid demand transp initial EJ[scenarios]

Units: EJ/Year

1<=>1. "CNG vehicles are currently slightly less efficient than equivalent gasoline vehicles while diesel vehicles enjoy a net advantage. In the future, however, improvements in spark ignition engines will bring all technologies much closer together" (IET JRC, 2014).

pct Imin[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C16')

pct Imin[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C16')

pct Imin[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C16')

pct Imin[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C16')

pct Imin[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C16')

pct Imin[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C16')

Units: Dmnl

Percentage defining the minimum energy intensity (Schenk and Moll equation). The same value is assumed for all sectors. If this percentage is set to 0, then the equation of Schenk and Moll equates the conventional expression of energy intensity.

PE demand for Transport initial EJ[scenarios]=

"I-TRANSP"[scenarios]*GDP[scenarios]

Units: EJ/Year

Primary energy demand of energy for the Transportation sector.

PE demand for Transport initial EJ delayed 1yr[scenarios]= DELAY FIXED (

PE demand for Transport initial EJ[scenarios], 1 , PE demand Transp 1989 EJ

)

Units: EJ/Year

Primary energy demand of the Transportation sector delayed 1 year.

PE demand Transp 1989 EJ=

66.88

Units: EJ

Primary energy demand of the Transportation sector in the year 1989. Source: IEA ETP (2010).

PE demand Transport after policies EJ[scenarios]=

demand gas for Transp EJ[scenarios]+real PE demand of liquids for Transp EJ [scenarios]

Units: EJ/Year

Primary energy demand for Transportation after policies (excluding electricity).

PE demand Transport after policies Mtoe[scenarios]=

PE demand Transport after policies EJ[scenarios]*MToe per EJ

Units: MToe/Year

Primary energy demand for Transportation after policies (excluding electricity).

propor gas transp losses=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C55')

Units: Dmnl

In IEA statistics, "natural gas to transport" includes several losses such as "pipeline transport, other transformation" (IEA ETP 2012).

real PE demand of liquids for Transp EJ[scenarios]=

MAX(Liquid demand transp initial EJ[scenarios]-Oil liquids saved by EVs EJ [scenarios]-Oil liquids saved by NGVs[scenarios],0)

Units: EJ/Year

Energy demand in form of liquids of Transportation sector after applying policies and technological shift.

real PED intensity of Transport[scenarios]=

PE demand Transport after policies EJ[scenarios]/GDP[scenarios]

Units: EJ/Tdollars

Primary energy demand (after policies and without electricity)

of the Transportation sector.

share liquids for Transp[scenarios]=

IF THEN ELSE(Total demand liquids EJ[scenarios]>0, real PE demand of liquids for Transp EJ [scenarios]/Total demand liquids EJ[scenarios],0)

Units: Dmnl

Share of liquids for Transportation. Condition to avoid error

when the total demand of liquids falls to zero (0.5 is an

arbitrary value).

"t I-TRANSP"[scenarios]=

Time dmnl[scenarios](Time)-2015

Units: Dmnl

Time (Schenk and Moll equation), taking as reference the last

year of "'a' historical I-TRANSP intensity" (2015).

Time dmnl[scenarios](

[(1990,1990)-(2100,2100)],(1990,1990),(1991,1991),(1992,1992),(1993,1993),
(1994,1994),(1995,1995),(1996,1996),(1997,1997),(1998,1998),(1999,1999),(2000
,2000),(2001,2001),(2002,2002),(2003,2003),(2004,2004),(2005,2005),(2006,2006
),(2007,2007),(2008,2008),(2009,2009),(2010,2010),(2011,2011),(2012,2012),(
2013,2013),(2014,2014),(2015,2015),(2016,2016),(2017,2017),(2018,2018),(2019
,2019),(2020,2020),(2021,2021),(2022,2022),(2023,2023),(2024,2024),(2025,2025
),(2026,2026),(2027,2027),(2028,2028),(2029,2029),(2030,2030),(2031,2031),(
2032,2032),(2033,2033),(2034,2034),(2035,2035),(2036,2036),(2037,2037),(2038
,2038),(2039,2039),(2040,2040),(2041,2041),(2042,2042),(2043,2043),(2044,2044
),(2045,2045),(2046,2046),(2047,2047),(2048,2048),(2049,2049),(2050,2050),(
2051,2051),(2052,2052),(2053,2053),(2054,2054),(2055,2055),(2056,2056),(2057
,2057),(2058,2058),(2059,2059),(2060,2060),(2061,2061),(2062,2062),(2063,2063
),(2064,2064),(2065,2065),(2066,2066),(2067,2067),(2068,2068),(2069,2069),(
2070,2070),(2071,2071),(2072,2072),(2073,2073),(2074,2074),(2075,2075),(2076
,2076),(2077,2077),(2078,2078),(2079,2079),(2080,2080),(2081,2081),(2082,2082
),(2083,2083),(2084,2084),(2085,2085),(2086,2086),(2087,2087),(2088,2088),(

2089,2089),(2090,2090),(2091,2091),(2092,2092),(2093,2093),(2094,2094),(2095
,2095),(2096,2096),(2097,2097),(2098,2098),(2099,2099),(2100,2100))

Units: Dmnl

Vector that assigns for every year the number of that same year.

"year 'a-TRANSP' projected reached"[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C13')

"year 'a-TRANSP' projected reached"[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C13')

"year 'a-TRANSP' projected reached"[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C13')

"year 'a-TRANSP' projected reached"[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C13')

"year 'a-TRANSP' projected reached"[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C13')

"year 'a-TRANSP' projected reached"[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C13')

Units: Year

Year when the projected improvement of primary energy intensity of the sector ("a-sector" value) is reached.

24. TRANSP – Alternative transport

Abundance electricity[scenarios]=

IF THEN ELSE(Total FE Elec generation TWh[scenarios]>Total FE Elec demand TWh [scenarios], 1, 1-((Total FE Elec demand TWh[scenarios]-Total FE Elec generation TWh [scenarios])/Total FE Elec demand TWh[scenarios]))

Units: Dmnl

The parameter abundance varies between (1;0). Abundance=1 while the supply covers the demand; the closest to 0 indicates a higher divergence between supply and demand.

abundance gas[scenarios]=

IF THEN ELSE(Total demand gas EJ[scenarios]<total gas extraction EJ[scenarios
], 1, 1-(Total demand gas EJ[scenarios]-total gas extraction EJ[scenarios])
/Total demand gas EJ[scenarios])

Units: Dmnl

The parameter abundance varies between (1;0). Abundance=1 while

the supply covers the demand; the closest to 0 indicates a
higher divergence between supply and demand.

Additional increase PE demand for Transp Elec EJ[scenarios]=
Increase Elec demand for Transp EJ[scenarios]+PE losses related to Elec Transp
[scenarios]
Units: EJ/Year
Increase of primary energy consumption by EVs (electricity
consumption + losses).

BEV adapt growth[scenarios]=
IF THEN ELSE(Time<2015, "BEV/HEV past share growth",IF THEN ELSE(Time<2020
, "BEV/HEV past share growth"+(P BEV growth[scenarios]*"effects shortage elec on BEV/HEV"
[scenarios]-"BEV/HEV past share growth")*(Time dmnl[scenarios](Time)-2015)/
5, P BEV growth[scenarios]*"effects shortage elec on BEV/HEV"[scenarios]))
Units: 1/Year
Adaptation from historic trends to projected trends.

BEV fraction of share available[scenarios]=
IF THEN ELSE(technological max pct of change>total share EV[scenarios], (technological max pct of change
-total share EV
[scenarios])/technological max pct of change, 0)
Units: Dmnl
Fraction of share available to shift to BEV.

BEV share[scenarios]= INTEG (
variation share BEV[scenarios],
0)
Units: Dmnl
Battery electric vehicles share of motor engines.

"BEV/HEV past share growth"=
GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C79')
Units: 1/Year
Average 2005-2015 share growth of BEV and HEV (EVI 2016).

current trends demand Elec for Transp[scenarios]=

PE demand for Transport initial EJ[scenarios]*Current trends electric transport share [scenarios]

Units: EJ/Year

Current trends of Demand of electricity for Transportation (EJ).

We assume that the share of current TPE demand of transport covered by electricity (excepting alternative policies) is maintained constant in the future. Since we extrapolate the current trends, the electricity consumption is not increased assuming that current trends are already included in the electricity consumption trend.

Current trends electric transport share[scenarios]= INTEG (

variation current trends elec transp share[scenarios],

share current trends Elec for Transp)

Units: **undefined**

Electric transport share excluding electric LDVs (currently mainly train).

"effects shortage elec on BEV/HEV"[scenarios]=

IF THEN ELSE(Abundance electricity[scenarios]>0.8, ((Abundance electricity [scenarios]-0.8)*5)^2, 0)

Units: Dmnl

The eventual scarcity of electricity would likely constrain the development of EVs. The proposed relationship avoids an abrupt limitation by introducing a range (1;0.8) in the electricity abundance that constrains the development of EVs.

effects shortage gas[scenarios]=

IF THEN ELSE(abundance gas[scenarios]>0.8, ((abundance gas[scenarios]-0.8) *5)^2, 0)

Units: Dmnl

The eventual scarcity of gas would likely constrain the development of NGVs/GTLs. The proposed relationship avoids an abrupt limitation by introducing a range (1;0.8) in the gas abundance that constrains the development of NGVs/GTLs.

EJ per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C5')

Units: EJ/TWh

Unit conversion (3.6 EJ=1000 TWh)

HEV adapt growth[scenarios]=

IF THEN ELSE(Time<2015, "BEV/HEV past share growth", IF THEN ELSE(Time<2020

, "BEV/HEV past share growth"+(P HEV growth[scenarios]*"effects shortage elec on BEV/HEV"

[scenarios]-"BEV/HEV past share growth")*(Time dmnl[scenarios](Time)-2015)/

5, P HEV growth[scenarios]*"effects shortage elec on BEV/HEV"[scenarios]))

Units: 1/Year

Adaptation from historic trends to projected trends.

HEV fraction of share available[scenarios]=

IF THEN ELSE(technological max pct of change>total share EV[scenarios], (technological max pct of change

-total share EV[scenarios])/technological max pct of change, 0)

Units: Dmnl

Fraction of share available to shift to HEV.

HEV share[scenarios]= INTEG (

variation share HEV[scenarios],

0)

Units: Dmnl

Hybrid electric vehicles share of motor engines.

"Historical share BEV+HEV"(

GET XLS LOOKUPS('inputs.xlsx', 'Constants', '25', 'C42'))

Units: Dmnl

Historical share of BEV and HEV. Source: EVI (2016, Table 6).

Since the number of BEVs and HEVs is similar at global level and

the statistics are aggregated, we assume that the historical

share is half for each alternative transportation mode. /*only

historical data of share from 2005 */

Historical share NGVs=

GET XLS LOOKUPS('inputs.xlsx', 'Constants', '25', 'C43')

Units: Dmnl

Historical share of NGVs. Source: IANGV

(http://www.iangv.org/current-ngv-stats/). /*only historical data of share from 2005 */

increase Elec demand EVs TWh[scenarios]=

Oil liquids saved by EVs EJ[scenarios]*K liquid Elec BEV TWh EJ

Units: TWh

Additional electricity demand for electric vehicles (BEVs and HEVs).

Increase Elec demand for Transp EJ[scenarios]=

increase Elec demand for Transp TWh[scenarios]*EJ per TWh

Units: EJ/Year

Additional electricity demand due to the shift alternative transport (BEV & HEV).

increase Elec demand for Transp TWh[scenarios]=

increase Elec demand EVs TWh[scenarios]

Units: TWh

Additional electricity demand by alternative transport (BEV & HEV). Since in this model version there are not other alternatives modes of transport that consume electricity (e.g. train), this variable matches with "increase E EV TWh".

K liquid Elec BEV TWh EJ=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C68')

Units: TWh/EJ

Consumption of electricity (TWh) of EV vs. the consumption of liquid fuels primary energy (EJ) for a LDV. If we compare the energy needs of electric vehicles with petrol vehicles of equal weight and power, (EABEV, 2008) gives a relationship of 1:3 favourable to electric vehicles (tank to wheel). See Technical Report.

Liquid demand transp initial EJ[scenarios]=

PE demand for Transport initial EJ[scenarios]*(1-propor gas transp losses)

-current trends demand Elec for Transp[scenarios]

Units: EJ/Year

Demand of liquids by the Transportation sector.

max NGV percent of change[scenarios]=

(1-total share EV[scenarios])

Units: Dmnl

NGVs can technically substitute all motor vehicles.

"Mb/d per EJ/year"=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C17')

Units: Mb*Year/(EJ*d)

Conversion between Mb/d to EJ/year.

NGV adapt growth[scenarios]=

IF THEN ELSE(Time<2015, NGV past share growth,IF THEN ELSE(Time<2020, NGV past share growth +(P NGV growth[scenarios]*effects shortage gas[scenarios]-NGV past share growth)*(Time dmnl[scenarios](Time)-2015)/5, P NGV growth[scenarios]*effects shortage gas [scenarios]))

Units: 1/Year

Adaptation from historic trends to projected trends.

NGV fraction of change available[scenarios]=

((max NGV percent of change[scenarios]-NGV share[scenarios])/max NGV percent of change [scenarios])

Units: Dmnl

Fraction of share available to shift to NGV.

NGV past share growth=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C80')

Units: 1/Year

Average 1994-2012 share growth of NGVs (IANGV:

http://www.iangv.org/current-ngv-stats/).

NGV share[scenarios]= INTEG (

variation share NGV[scenarios],

0)

Units: Dmnl

Natural gas vehicles share of motor engines. Despite the strong growth in the past decade, the total number of 16.7 million NGVs (http://www.iangv.org/current-ngv-stats/) still pales in comparison to a total worldwide number of around 1,150 million motor vehicles in 2009 (World Bank database, 2014). - 1.45% of total.

Oil liquids saved by EVs EJ[scenarios]=

Liquid demand transp initial EJ[scenarios]*(BEV share[scenarios]+(1/3)*HEV share [scenarios])

Units: EJ/Year

Oil liquids saved by electric vehicles (BEV and HEV).

Oil liquids saved by EVs kbd[scenarios]=

Oil liquids saved by EVs EJ[scenarios]*"Mb/d per EJ/year"*1000

Units: kboe/d

Oil liquids saved by electric vehicles (BEV and HEV).

Oil liquids saved by NGVs[scenarios]=

NGV share[scenarios]*Liquid demand transp initial EJ[scenarios]

Units: EJ/Year

1<=>1. "CNG vehicles are currently slightly less efficient than equivalent gasoline vehicles while diesel vehicles enjoy a net advantage. In the future, however, improvements in spark ignition engines will bring all technologies much closer together" (IET JRC, 2014).

P BEV growth[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C61')

P BEV growth[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C61')

P BEV growth[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C61')

P BEV growth[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C61')

P BEV growth[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C61')

P BEV growth[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C61')

Units: 1/Year

BEV annual share growth of total motor vehicles from 2015.

P elec transp share[scenarios]=

0

Units: **undefined**

Growth in the share of electric transportation (excluding
electric LDVs).

P HEV growth[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C62')

P HEV growth[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C62')

P HEV growth[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C62')

P HEV growth[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C62')

P HEV growth[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C62')

P HEV growth[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C62')

Units: 1/Year

HEV annual share growth of total motor vehicles from 2015.

P NGV growth[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C63')

P NGV growth[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C63')

P NGV growth[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C63')

P NGV growth[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C63')

P NGV growth[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C63')

P NGV growth[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C63')

Units: 1/Year

NGV annual share growth of total motor vehicles from 2015.

PE demand for Transport initial EJ[scenarios]=

"I-TRANSP"[scenarios]*GDP[scenarios]

Units: EJ/Year

Primary energy demand of energy for the Transportation sector.

PE Elec for Transp EJ[scenarios]=

current trends demand Elec for Transp[scenarios]+PE losses related to Elec Transp [scenarios]+Increase Elec demand for Transp EJ [scenarios]

Units: EJ/Year

Primary energy required to cover the electricity demand of Transportation. It includes current electric transport shares (around 1% dedicated to train), increase due to alternative modes of transport and the generation and distribution losses associated to the latter increase.

PE losses related to Elec Transp[scenarios]=

(increase Elec demand for Transp TWh[scenarios]*EJ per TWh/Total FE Elec demand EJ [scenarios])*Total electrical losses EJ[scenarios]

Units: EJ/Year

Allocation of the electricity losses (generation + distribution) corresponding to the alternative modes of transport using electricity ("increase Elec demand for Transp").

Savings PE Transport EJ[scenarios]=

Total liquid saved by Elec EJ[scenarios]-Additional increase PE demand for Transp Elec EJ [scenarios]

Units: EJ/Year

Savings in primary energy after the shift to EVs vehicles.

share current trends Elec for Transp=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C36')

Units: Dmnl

Share of current TPE demand of transport covered by electricity (around 1%, mainly trains).

technological max pct of change=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C67')

Units: Dmnl

Around 47% of the energy consumption in transportation sector is

from LDVs.

Time dmnl[scenarios](

[(1990,1990)-(2100,2100)],(1990,1990),(1991,1991),(1992,1992),(1993,1993),
(1994,1994),(1995,1995),(1996,1996),(1997,1997),(1998,1998),(1999,1999),(2000
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2013,2013),(2014,2014),(2015,2015),(2016,2016),(2017,2017),(2018,2018),(2019
,2019),(2020,2020),(2021,2021),(2022,2022),(2023,2023),(2024,2024),(2025,2025
),(2026,2026),(2027,2027),(2028,2028),(2029,2029),(2030,2030),(2031,2031),(
2032,2032),(2033,2033),(2034,2034),(2035,2035),(2036,2036),(2037,2037),(2038
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2051,2051),(2052,2052),(2053,2053),(2054,2054),(2055,2055),(2056,2056),(2057
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),(2064,2064),(2065,2065),(2066,2066),(2067,2067),(2068,2068),(2069,2069),(
2070,2070),(2071,2071),(2072,2072),(2073,2073),(2074,2074),(2075,2075),(2076
,2076),(2077,2077),(2078,2078),(2079,2079),(2080,2080),(2081,2081),(2082,2082
),(2083,2083),(2084,2084),(2085,2085),(2086,2086),(2087,2087),(2088,2088),(
2089,2089),(2090,2090),(2091,2091),(2092,2092),(2093,2093),(2094,2094),(2095
,2095),(2096,2096),(2097,2097),(2098,2098),(2099,2099),(2100,2100))

Units: Dmnl

Vector that assigns for every year the number of that same year.

Total liquid saved by Elec EJ[scenarios]=

Oil liquids saved by EVs EJ[scenarios]

Units: EJ/Year

Total liquids saved by shift to electric modes of transport.

total share EV[scenarios]=

BEV share[scenarios]+HEV share[scenarios]

Units: Dmnl

Total penetration share of electric vehicles.

variation current trends elec transp share[scenarios]=

Current trends electric transport share[scenarios]*P elec transp share[scenarios

]

Units: **undefined**

Annual variation of electric transport share excluding electric

LDVs.

variation share BEV[scenarios]=

IF THEN ELSE(Time<2015,("Historical share BEV+HEV"(Time+1)-"Historical share BEV+HEV"

(Time))/2, BEV adapt growth[scenarios]*BEV fraction of share available[scenarios

]*BEV share[scenarios])

Units: 1/Year

Variation of the share of BEVs in relation to the motor vehicles.

variation share HEV[scenarios]=

IF THEN ELSE(Time<2015,("Historical share BEV+HEV"(Time+1)-"Historical share BEV+HEV"

(Time))/2, HEV share[scenarios]*HEV fraction of share available[scenarios]*

HEV adapt growth[scenarios])

Units: 1/Year

Variation of the share of HEVs in relation to the motor vehicles.

variation share NGV[scenarios]=

IF THEN ELSE(Time<2011,(Historical share NGVs(Time+1)-Historical share NGVs

(Time)), NGV adapt growth[scenarios]*NGV fraction of change available[scenarios

]*NGV share[scenarios])

Units: 1/Year

Variation of the share of NGVs in relation to the motor vehicles.

25. IB – Industry & Buildings energy demand

"'a' historical I-IB":INTERPOLATE::=

GET XLS DATA('inputs.xlsx', 'Constants', '25', 'C32')

Units: Dmnl

Historical IB primary energy intensity was calculated internally

in the model for the calibration period (1990-2010) as the
subtraction of Total energy minus Transport energy and
Electrical sector (generation and losses).

"'a' I-IB projection"[BAU]=
GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C14')
"'a' I-IB projection"[SCEN1]=
GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C14')
"'a' I-IB projection"[SCEN2]=
GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C14')
"'a' I-IB projection"[SCEN3]=
GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C14')
"'a' I-IB projection"[SCEN4]=
GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C14')
"'a' I-IB projection"[User defined]=
GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C14')
Units: Dmnl
Evolution depending on the scenario of the "a" parameter, which
represents the annual PE intensity improvement of the sector,
i.e. indirectly the Annual Efficiency Improvements (a=1-AEI),
Constant value over time.

"Adapt 'a' I-IB"[scenarios]=
IF THEN ELSE(Time<2008, "'a' historical I-IB",IF THEN ELSE(Time<"year 'a-IB' projected reached"
[scenarios],"'a' historical I-IB"+("'a' I-IB projection"[scenarios]-"'a' historical I-IB"
)*(Time-2008)/("year 'a-IB' projected reached"[scenarios]-2008), "'a' I-IB projection"
[scenarios]))
Units: Dmnl
Smoothing transition for the parameter "a" between the
historical trends and the projected trend. The projected trend
is reached at "year 'a-sector' projected reached".

GDP[scenarios]=
GDPcap[scenarios]*Population[scenarios]/dollars to Tdollars
Units: Tdollars/Year
Global Domestic Product.

GDP delayed 1yr[scenarios]= DELAY FIXED (

GDP[scenarios], 1, 39.435)

Units: Tdollars/Year

GDP projection delayed 1 year. Data from World Bank -->

GDP(1989)=39.435 T$ US2011. .

"I-IB delayed 1yr"[scenarios]=

PE demand for IB delayed 1yr[scenarios]/GDP delayed 1yr[scenarios]

Units: EJ/Tdollars

Energy intensity of the Industry & Buildings sector delayed 1 year.

"I-IB min"[scenarios]=

"I-IB(1990)"*pct Imin[scenarios]

Units: EJ/Tdollars

Horizontal asymptote that represents the minimum value of the future primary energy intensity of the Industry and Buildings sector (following Schenk and Moll, 2007 equation).

"I-IB"[scenarios]=

IF THEN ELSE(Time<2008, "'a' historical I-IB"*"I-IB delayed 1yr"[scenarios
] ,"I-IB min"[scenarios]+("I-IB(t=0), i.e. 2007"-"I-IB min"[scenarios])*"Adapt 'a' I-IB"
[scenarios]^"t I-IB"[scenarios])

Units: EJ/Tdollars

Primary energy consumption intensity of the Industry and Buildings sector. Equation as a physical indicator as proposed by (Schenk and Moll, 2007) I_t=I_min+(I_(t=0)-I_min)·a^t Due to the lack of data at the time of the construction of the model, the parameter "a" was calculated internally in the model for the calibration period (1990-2010) as the subtraction of Total energy minus Transport and Electrical sector (generation and losses).

"I-IB(1990)"=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C106')

Units: EJ/Tdollars

Value of the primary energy intensity of the Industry and

Buildings sector in 1990.

"I-IB(t=0), i.e. 2007"=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C103')

Units: EJ/Tdollars

Value of the primary energy intensity of the Industry and

Buildings sector in the initial year (2007) to apply Schenk and

Moll, 2007 equation.

pct Imin[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C16')

pct Imin[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C16')

pct Imin[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C16')

pct Imin[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C16')

pct Imin[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C16')

pct Imin[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C16')

Units: Dmnl

Percentage defining the minimum energy intensity (Schenk and

Moll equation). The same value is assumed for all sectors. If

this percentage is set to 0, then the equation of Schenk and

Moll equates the conventional expression of energy intensity.

PE demand for IB delayed 1yr[scenarios]= DELAY FIXED (

PE demand for IB initial EJ[scenarios], 1, 140)

Units: EJ/Year

Primary energy demand of the Industry and Buildings sector

delayed 1 year (adjusted value).

PE demand for IB initial EJ[scenarios]=

"I-IB"[scenarios]*GDP[scenarios]

Units: EJ

Primary energy demand of energy for Industry and Buildings sector (without electricity)..

"t I-IB"[scenarios]=

Time dmnl[scenarios](Time)-2007

Units: Dmnl

Time (Schenk and Moll equation), taking as reference the last

year of "'a' historical I-IB intensity" (2007).

Time dmnl[scenarios](

[(1990,1990)-(2100,2100)],(1990,1990),(1991,1991),(1992,1992),(1993,1993),
(1994,1994),(1995,1995),(1996,1996),(1997,1997),(1998,1998),(1999,1999),(2000
,2000),(2001,2001),(2002,2002),(2003,2003),(2004,2004),(2005,2005),(2006,2006
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2013,2013),(2014,2014),(2015,2015),(2016,2016),(2017,2017),(2018,2018),(2019
,2019),(2020,2020),(2021,2021),(2022,2022),(2023,2023),(2024,2024),(2025,2025
),(2026,2026),(2027,2027),(2028,2028),(2029,2029),(2030,2030),(2031,2031),(
2032,2032),(2033,2033),(2034,2034),(2035,2035),(2036,2036),(2037,2037),(2038
,2038),(2039,2039),(2040,2040),(2041,2041),(2042,2042),(2043,2043),(2044,2044
),(2045,2045),(2046,2046),(2047,2047),(2048,2048),(2049,2049),(2050,2050),(
2051,2051),(2052,2052),(2053,2053),(2054,2054),(2055,2055),(2056,2056),(2057
,2057),(2058,2058),(2059,2059),(2060,2060),(2061,2061),(2062,2062),(2063,2063
),(2064,2064),(2065,2065),(2066,2066),(2067,2067),(2068,2068),(2069,2069),(
2070,2070),(2071,2071),(2072,2072),(2073,2073),(2074,2074),(2075,2075),(2076
,2076),(2077,2077),(2078,2078),(2079,2079),(2080,2080),(2081,2081),(2082,2082
),(2083,2083),(2084,2084),(2085,2085),(2086,2086),(2087,2087),(2088,2088),(
2089,2089),(2090,2090),(2091,2091),(2092,2092),(2093,2093),(2094,2094),(2095
,2095),(2096,2096),(2097,2097),(2098,2098),(2099,2099),(2100,2100))

Units: Dmnl

Vector that assigns for every year the number of that same year.

"year 'a-IB' projected reached"[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C15')

"year 'a-IB' projected reached"[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C15')

"year 'a-IB' projected reached"[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C15')

"year 'a-IB' projected reached"[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C15')

"year 'a-IB' projected reached"[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C15')

"year 'a-IB' projected reached"[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C15')

Units: Year

Year when the projected improvement of primary energy intensity

of the sector ("a-sector" value) is reached.

26. IB – Industry & Buildings sector

GDP[scenarios]=

GDPcap[scenarios]*Population[scenarios]/dollars to Tdollars

Units: Tdollars/Year

Global Domestic Product.

"PE demand Build after RES+efficiency EJ"[scenarios]=

PE demand gas for Buildings EJ[scenarios]+PE demand coal for Buildings EJ[
scenarios]+PE demand liquids for Buildings EJ[scenarios]+PE supply thermal RES for Build
[scenarios]

Units: EJ

Primary energy in the Buildings sector after accounting for RES

and efficiency improvements.

PE demand Buildings EJ[scenarios]=

PE demand for IB initial EJ[scenarios]*"share Buildings/IB"[scenarios]

Units: EJ

Primary energy demand by the Buildings sector (without

electricity).

PE demand coal for Buildings EJ[scenarios]=

PE demand FF Buildings[scenarios]*"share incr coal/FF for Build"[scenarios
]/tot shares incr Build[scenarios]

Units: EJ/Year

Primary energy demand of coal of the Buildings sector.

PE demand coal for IB[scenarios]=

PE demand coal for Buildings EJ[scenarios]+PE demand coal for Industry EJ[
scenarios]
Units: **undefined**

PE demand coal for Industry EJ[scenarios]=
PE demand FF Industry[scenarios]*"share incr coal/FF for Ind"[scenarios]/tot shares incr Ind
[scenarios]
Units: EJ/Year
Primary energy demand of coal of the Industry sector.

PE demand FF Buildings[scenarios]=
MAX(PE demand Buildings EJ[scenarios]-PE supply thermal RES for Build[scenarios
],1)
Units: EJ
Primary energy demand covered by fossil fuels in the Buildings
sector (without electricity). We force the maximum to be
positive in order to avoid divisions by zero.

PE demand FF Industry[scenarios]=
MAX(PE demand Industry EJ[scenarios]-PE supply thermal RES for Indus[scenarios
],1)
Units: EJ
Primary energy demand covered by fossil fuels in the Industry
sector (without electricity). We force the maximum to be
positive in order to avoid divisions by zero.

PE demand for IB after RES EJ[scenarios]=
"PE demand Ind after RES+efficiency EJ"[scenarios]+"PE demand Build after RES+efficiency EJ"
[scenarios]
Units: EJ/Year
Primary energy demand for Industry and Buildings sector after
policies.

PE demand for IB initial EJ[scenarios]=
"I-IB"[scenarios]*GDP[scenarios]
Units: EJ
Primary energy demand of energy for Industry and Buildings

sector (without electricity)..

PE demand gas for Buildings EJ[scenarios]=

PE demand FF Buildings[scenarios]*"share incr gas/FF for Build"[scenarios]

/tot shares incr Build[scenarios]

Units: EJ/Year

Primary energy demand of gas of the Buildings sector.

PE demand gas for IB[scenarios]=

PE demand gas for Buildings EJ[scenarios]+PE demand gas for Industry EJ[scenarios

]

Units: **undefined**

PE demand gas for Industry EJ[scenarios]=

PE demand FF Industry[scenarios]*"share incr gas/FF for Ind"[scenarios]/tot shares incr Ind

[scenarios]

Units: EJ/Year

Primary energy demand of gas of the Industry sector.

"PE demand Ind after RES+efficiency EJ"[scenarios]=

PE demand coal for Industry EJ[scenarios]+PE demand gas for Industry EJ[scenarios

]+PE demand liquids for Industry EJ[scenarios]+PE supply thermal RES for Indus

[scenarios]

Units: EJ/Year

Primary energy in the Industry sector after accounting for RES

and efficiency improvements.

PE demand Industry EJ[scenarios]=

IF THEN ELSE(Time<2015, PE demand for IB initial EJ[scenarios]*"share Industry/IB historic"

, PE demand for IB initial EJ[scenarios]*"share Industry/IB scenario"[scenarios

])

Units: EJ

Primary energy demand by the Industry sector (without

electricity).

PE demand liquids for Buildings EJ[scenarios]=

PE demand FF Buildings[scenarios]*"share incr liquids/FF for Build"[scenarios

]/tot shares incr Build[scenarios]

Units: EJ/Year

Primary energy demand of oil of the Buildings sector.

PE demand liquids for IB[scenarios]=

PE demand liquids for Buildings EJ[scenarios]+PE demand liquids for Industry EJ [scenarios]

Units: **undefined**

PE demand liquids for Industry EJ[scenarios]=

PE demand FF Industry[scenarios]*"share incr liquids/FF for Ind"[scenarios]/tot shares incr Ind[scenarios]

Units: EJ/Year

Primary energy demand of oil of the Industry sector.

PE supply thermal RES for Build[scenarios]=

thermal RES supply for Build[scenarios]

Units: EJ

Primary energy supply of thermal RES for sector Buildings.

PE supply thermal RES for Indus[scenarios]=

thermal RES supply for Ind[scenarios]

Units: EJ

Primary energy supply of thermal RES for sector Industry.

real PE intensity Build[scenarios]=

"PE demand Build after RES+efficiency EJ"[scenarios]/GDP[scenarios]

Units: EJ/Tdollars

real PE intensity Indus[scenarios]=

"PE demand Ind after RES+efficiency EJ"[scenarios]/GDP[scenarios]

Units: EJ/Tdollars

real PED intensity IB[scenarios]=

PE demand for IB after RES EJ[scenarios]/GDP[scenarios]

Units: EJ/Tdollars

Primary energy demand intensity of the Industry and Buildings sector after policies.

"share Buildings/IB"[scenarios]=

IF THEN ELSE(Time<2015, (1-"share Industry/IB historic"), (1-"share Industry/IB scenario"

[scenarios]))

Units: Dmnl

Round average share of primary energy consumption of the sector

Buildings in relation to Industry+Buildings in the last years

(25%). See Technical Report.

share coal for Build[scenarios]=

1-share gas for Build[scenarios]-share liquids for Build[scenarios]

Units: Dmnl

Share of coal to cover the fossil fuel demand of the Buildings

sector. Adaptation of shares from WoLiM 1.0 (Ref: WoLiM 1.0 &

IEOs (see Technical Report)). Share constant after 2011.

share coal for Ind[scenarios]=

IF THEN ELSE(Time<2003, 0.28 ,

(IF THEN ELSE(Time<2011,0.0075 *Time dmnl[scenarios](Time)-14.7425 ,

(IF THEN ELSE(Time<2016 , 0.34 ,

(IF THEN ELSE(Time<2018 ,-0.015*Time dmnl[scenarios](Time)+30.58 ,0.3))))

)))

Units: Dmnl

Share of coal to cover the fossil fuel demand of the Industry

sector. (Ref: WoLiM 1.0 & IEOs (see Technical Report)).

share gas for Build[scenarios]=

IF THEN ELSE(Time<2003, 0.56 , IF THEN ELSE(Time<2007, 0.015*Time dmnl[scenarios

](Time)-29.485 ,0.595))

Units: Dmnl

Share of gas to cover the fossil fuel demand of the Buildings

sector. (Ref: WoLiM 1.0 & IEOs (see Technical Report)). Share

constant after 2007.

share gas for Ind[scenarios]=

IF THEN ELSE(Time<2003,0.3 , (IF THEN ELSE(Time<2011, (-0.0038*Time dmnl[scenarios

](Time)+7.91), 0.27)))

Units: Dmnl

Share of gas to cover the fossil fuel demand of the Industry sector (Ref: WoLiM 1.0 & IEOs (see Technical Report)). Share constant after 2011.

"share incr coal/FF for Build"[scenarios]=

IF THEN ELSE(PE demand FF Buildings[scenarios]>0,(PE demand Buildings EJ[scenarios]/PE demand FF Buildings[scenarios])*share coal for Build[scenarios], 0)

Units: Dmnl

Share increase of coal to cover the fossil fuel demand of the Buildings sector.

"share incr coal/FF for Ind"[scenarios]=

IF THEN ELSE(PE demand FF Industry[scenarios]>0, (PE demand Industry EJ[scenarios]/PE demand FF Industry[scenarios])*share coal for Ind[scenarios],0)

Units: Dmnl

Share increase of coal to cover the fossil fuel demand of the Industry sector. Adaptation of shares from WoLiM 1.0 (Ref: WoLiM 1.0 & IEOs (see Technical Report)). Share constant after 2011.

"share incr gas/FF for Build"[scenarios]=

IF THEN ELSE(PE demand FF Buildings[scenarios]>0,(PE demand Buildings EJ[scenarios]/PE demand FF Buildings[scenarios])*share gas for Build[scenarios], 0)

Units: Dmnl

Share of gas to cover the fossil fuel demand of the Buildings sector. Adaptation of shares from WoLiM 1.0 (Ref: WoLiM 1.0 & IEOs (see Technical Report)). Share constant after 2011.

"share incr gas/FF for Ind"[scenarios]=

IF THEN ELSE(PE demand FF Industry[scenarios]>0,(PE demand Industry EJ[scenarios]/PE demand FF Industry[scenarios])*share gas for Ind[scenarios], 0)

Units: Dmnl

Share increase of gas to cover the fossil fuel demand of the Industry sector. Adaptation of shares from WoLiM 1.0 (Ref: WoLiM 1.0 & IEOs (see Technical Report)). Share constant after 2011.

"share incr liquids/FF for Build"[scenarios]=

IF THEN ELSE(PE demand FF Buildings[scenarios]>0, (PE demand Buildings EJ[scenarios]/PE demand FF Buildings[scenarios])*share liquids for Build[scenarios],0)

Units: Dmnl

Share increase of liquids to cover the fossil fuel demand of the Buildings sector. Adaptation of shares from WoLiM 1.0 (Ref: WoLiM 1.0 & IEOs (see Technical Report)). Share constant after 2011.

"share incr liquids/FF for Ind"[scenarios]=

IF THEN ELSE(PE demand FF Industry[scenarios]>0,(PE demand Industry EJ[scenarios]/PE demand FF Industry[scenarios])*share liquids for Ind[scenarios], 0)

Units: Dmnl

Share increase of liquids to cover the fossil fuel demand of the Industry sector.

"share Industry/IB historic"=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C37')

Units: Dmnl

Round average share of primary energy consumption of the sector Industry in relation to Industry+Buildings in the last years (75%). See Technical Report.

"share Industry/IB scenario"[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C17')

"share Industry/IB scenario"[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C17')

"share Industry/IB scenario"[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C17')

"share Industry/IB scenario"[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C17')

"share Industry/IB scenario"[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C17')

"share Industry/IB scenario"[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C17')

Units: Dmnl

Projected share of primary energy consumption of the sector Industry in relation to Industry+Buildings (historical rounded value: 75%, see Technical Report).

share liquids for Build[scenarios]=

IF THEN ELSE(Time<2003,0.35, IF THEN ELSE(Time<2007,-0.0225*Time dmnl[scenarios](Time)+45.4175,0.26))

Units: Dmnl

Share of liquids convering the PE consumption of the Buildings sector (Ref: WoLiM 1.0 & IEOs (see Technical Report)). Share constant after 2007.

share liquids for Ind[scenarios]=

1-share coal for Ind[scenarios]-share gas for Ind[scenarios]

Units: Dmnl

Share of liquids to cover the fossil fuel demand of the Industry sector.

share PE RES for Buildings[scenarios]=

PE supply thermal RES for Build[scenarios]/(PE supply thermal RES for Build [scenarios]+PE demand Buildings EJ[scenarios])

Units: Dmnl

Share of RES supply in the sector Buildings (primary energy).

share PE RES for Industry[scenarios]=

PE supply thermal RES for Indus[scenarios]/(PE supply thermal RES for Indus [scenarios]+PE demand Industry EJ[scenarios])

Units: Dmnl

Share of RES supply in the sector Industry (primary energy).

Time dmnl[scenarios](

[(1990,1990)-(2100,2100)],(1990,1990),(1991,1991),(1992,1992),(1993,1993),(1994,1994),(1995,1995),(1996,1996),(1997,1997),(1998,1998),(1999,1999),(2000 ,2000),(2001,2001),(2002,2002),(2003,2003),(2004,2004),(2005,2005),(2006,2006),(2007,2007),(2008,2008),(2009,2009),(2010,2010),(2011,2011),(2012,2012),(2013,2013),(2014,2014),(2015,2015),(2016,2016),(2017,2017),(2018,2018),(2019 ,2019),(2020,2020),(2021,2021),(2022,2022),(2023,2023),(2024,2024),(2025,2025

),(2026,2026),(2027,2027),(2028,2028),(2029,2029),(2030,2030),(2031,2031),(
2032,2032),(2033,2033),(2034,2034),(2035,2035),(2036,2036),(2037,2037),(2038
,2038),(2039,2039),(2040,2040),(2041,2041),(2042,2042),(2043,2043),(2044,2044
),(2045,2045),(2046,2046),(2047,2047),(2048,2048),(2049,2049),(2050,2050),(
2051,2051),(2052,2052),(2053,2053),(2054,2054),(2055,2055),(2056,2056),(2057
,2057),(2058,2058),(2059,2059),(2060,2060),(2061,2061),(2062,2062),(2063,2063
),(2064,2064),(2065,2065),(2066,2066),(2067,2067),(2068,2068),(2069,2069),(
2070,2070),(2071,2071),(2072,2072),(2073,2073),(2074,2074),(2075,2075),(2076
,2076),(2077,2077),(2078,2078),(2079,2079),(2080,2080),(2081,2081),(2082,2082
),(2083,2083),(2084,2084),(2085,2085),(2086,2086),(2087,2087),(2088,2088),(
2089,2089),(2090,2090),(2091,2091),(2092,2092),(2093,2093),(2094,2094),(2095
,2095),(2096,2096),(2097,2097),(2098,2098),(2099,2099),(2100,2100))

Units: Dmnl

Vector that assigns for every year the number of that same year.

tot shares incr Build[scenarios]=

"share incr coal/FF for Build"[scenarios]+"share incr gas/FF for Build"[scenarios
]+"share incr liquids/FF for Build"[scenarios]

Units: Dmnl

Total of shares increase to scale down the shares.

tot shares incr Ind[scenarios]=

"share incr coal/FF for Ind"[scenarios]+"share incr gas/FF for Ind"[scenarios
]+"share incr liquids/FF for Ind"[scenarios]

Units: Dmnl

Total of shares increase to scale down the shares.

27. TPED by fuel

extraction uranium EJ[scenarios]=

MIN(MIN(PE demand uranium EJ[scenarios], max extraction uranium EJ[scenarios
]), PE Elec gen nuclear capacity available EJ[
scenarios])

Units: EJ/Year

Annual extraction of uranium.

PE Elec generation from RES EJ[scenarios]=

PE BioW for Elec generation EJ[scenarios]+(PE geot for Elec generation EJ[

scenarios]+PE hydro for Elec generation EJ

[scenarios]+PE oceanic for Elec generation EJ[scenarios]+PE solar for Elec generation EJ

[scenarios]+PE onshore wind for Elec generation EJ

[scenarios]+PE offshore wind for Elec generation EJ[scenarios])/RES to fossil accounting

[scenarios]

Units: EJ/Year

Primary energy from RES electricity generation. For all sources

excepting "Bio" the factor "RES to fossil accounting" is applied

for the equivalent primary energy.

"PE supply RES non-Elec EJ"[scenarios]=

"PE supply from RES non-elec without trad bioE EJ"[scenarios]+PE traditional biomass EJ

[scenarios]

Units: EJ/Year

Primary energy (non electricity) from RES, including traditional

biomass.

Total demand coal EJ[scenarios]=

Total demand coal without CTL[scenarios]+demand coal for CTL EJ[scenarios]

Units: EJ/Year

Total demand of coal.

Total demand gas EJ[scenarios]=

demand gas for GTL EJ[scenarios]+Total demand gas without GTL[scenarios]

Units: EJ/Year

Total demand of natural gas (EJ).

Total demand oil EJ[scenarios]=

Total demand liquids EJ[scenarios]-Other liquids extraction EJ[scenarios]

Units: EJ/Year

Total oil (conventional and unconventional) demand .

TPED by fuel[scenarios]=

extraction uranium EJ[scenarios]+"PE supply RES non-Elec EJ"[scenarios]+PE Elec generation from RES EJ

[scenarios]+Total demand oil EJ

[scenarios]+Total demand coal EJ[scenarios]+Total demand gas EJ[scenarios]

Units: EJ/Year

Total primary energy demand by fuel.

28. TPED by sector

Additional PE production of bioenergy for biofuels[scenarios]=

PE biomass for biofuels production EJ[scenarios]-Oil liquids saved by biofuels EJ [scenarios]

Units: EJ/Year

Additional primary energy demand of bioenergy (NPP) for biofuels in relation to the PEavail. We assume than 1 unit of energy of biofuels substitutes 1 unit of energy of oil.

"Additional PE production of CTL+GTL for liquids"[scenarios]=

demand coal for CTL EJ[scenarios]+demand gas for GTL EJ[scenarios]-"CTL+GTL production EJ"[scenarios]

Units: EJ/Year

Additional primary energy production of CTL and GTL for liquids. We need to account for this difference since the oil replaced by CTL liquids is accounted for primary energy in WoLiM, while there are additional losses to process coal to obtain CTL (required to balance the TPES with the TPED).

check TPED[scenarios]=

(TPED by sector EJ[scenarios]-TPED by fuel[scenarios])*100/TPED by fuel[scenarios]

Units: percent

Comparison between TPED by fuel and TPED by sector (they should correspond).

GDP[scenarios]=

GDPcap[scenarios]*Population[scenarios]/dollars to Tdollars

Units: Tdollars/Year

Global Domestic Product.

"PE demand Build after RES+efficiency EJ"[scenarios]=

PE demand gas for Buildings EJ[scenarios]+PE demand coal for Buildings EJ[scenarios]+PE demand liquids for Buildings EJ[scenarios]+PE supply thermal RES for Build

[scenarios]

Units: EJ

Primary energy in the Buildings sector after accounting for RES

and efficiency improvements.

"PE demand Ind after RES+efficiency EJ"[scenarios]=

PE demand coal for Industry EJ[scenarios]+PE demand gas for Industry EJ[scenarios

]+PE demand liquids for Industry EJ[scenarios]+PE supply thermal RES for Indus

[scenarios]

Units: EJ/Year

Primary energy in the Industry sector after accounting for RES

and efficiency improvements.

PE demand Transport after policies EJ[scenarios]=

demand gas for Transp EJ[scenarios]+real PE demand of liquids for Transp EJ

[scenarios]

Units: EJ/Year

Primary energy demand for Transportation after policies

(excluding electricity).

PE traditional biomass EJ[scenarios]=

Population[scenarios]*share global pop dependent on trad biomass[scenarios

]*PEpc consumption people depending on trad biomass

Units: EJ/Year

Annual primary energy consumption of traditional biomass.

real TPED intensity[scenarios]=

TPED by sector EJ[scenarios]/GDP[scenarios]

Units: EJ/Tdollars

Total primary energy demand intensity after policies.

share dem Build vs TPED[scenarios]=

"PE demand Build after RES+efficiency EJ"[scenarios]/TPED by sector EJ[scenarios

]

Units: Dmnl

Share of TPED for Buildings.

share dem Elec losses vs TPED[scenarios]=

Total gen losses demand for Elec EJ[scenarios]/TPED by sector EJ[scenarios

]

Units: Dmnl

Share of TPED for electricity losses (depending from electricity

demand).

share dem Elec vs TPED[scenarios]=

Total FE Elec demand EJ[scenarios]/TPED by sector EJ[scenarios]

Units: Dmnl

Share of TPED for Electricity.

share dem Ind vs TPED[scenarios]=

"PE demand Ind after RES+efficiency EJ"[scenarios]/TPED by sector EJ[scenarios

]

Units: Dmnl

Share of TPED for Industry.

share dem trad biomass vs TPED[scenarios]=

PE traditional biomass EJ[scenarios]/TPED by sector EJ[scenarios]

Units: Dmnl

Share of TPED for traditional biomass.

share dem Transp vs TPED[scenarios]=

PE demand Transport after policies EJ[scenarios]/TPED by sector EJ[scenarios

]

Units: Dmnl

Share of TPED for Transportation.

Total FE Elec demand EJ[scenarios]=

Total FE Elec demand TWh[scenarios]*EJ per TWh

Units: EJ/Year

Electricity demand generation (final energy, includes

distribution losses).

Total gen losses demand for Elec EJ[scenarios]=

PE demand gas for Elec EJ[scenarios]*(1-efficiency gas for electricity)+PE demand coal for Elec EJ [scenarios]*(1-efficiency coal for electricity)+PE demand liquids for Elec EJ

[scenarios]*(1-efficiency liquids for electricity)+PE losses uranium for Elec EJ

[scenarios]+PE losses BioW for Elec EJ[scenarios]

Units: EJ/Year

Total generation losses associated to electricity demand.

Total PE for electricity consumption EJ[scenarios]=

Total FE Elec demand EJ[scenarios]+Elec gen related losses EJ[scenarios]

Units: EJ/Year

Total primary energy for electricity consumption (EJ).

TPED by fuel[scenarios]=

extraction uranium EJ[scenarios]+"PE supply RES non-Elec EJ"[scenarios]+PE Elec generation from RES EJ

[scenarios]+Total demand oil EJ

[scenarios]+Total demand coal EJ[scenarios]+Total demand gas EJ[scenarios]

Units: EJ/Year

Total primary energy demand by fuel.

TPED by sector EJ[scenarios]=

Total FE Elec demand EJ[scenarios]+Total gen losses demand for Elec EJ[scenarios

]+PE traditional biomass EJ[scenarios]+PE demand Transport after policies EJ

[scenarios]+"PE demand Ind after RES+efficiency EJ"[scenarios]+"PE demand Build after RES+efficiency EJ"

[scenarios]+"Additional PE production of CTL+GTL for liquids"

[scenarios]

Units: EJ/Year

Total primary energy demand by sector after policies.

29. RESOURCES – Oil & liquid extraction

abundance liquids[scenarios]=

IF THEN ELSE((Total demand liquids EJ[scenarios])<(Liquids extraction EJ[

scenarios]), 1, 1-((Total demand liquids EJ[scenarios]-Liquids extraction EJ

[scenarios])/Total demand liquids EJ[scenarios]))

Units: Dmnl

The parameter abundance varies between (1;0). Abundance=1 while

the supply covers the demand; the closest to 0 indicates a

higher divergence between supply and demand.

abundance total oil[scenarios]=

IF THEN ELSE(Total demand oil EJ[scenarios]<total oil extraction EJ[scenarios

], 1,

1-(Total demand oil EJ[scenarios]-total oil extraction EJ[scenarios])/Total demand oil EJ

[scenarios])

Units: Dmnl

The parameter abundance varies between (1;0). Abundance=1 while

the supply covers the demand; the closest to 0 indicates a

higher divergence between supply and demand.

check liquids[scenarios]=

(Total demand liquids EJ[scenarios]-Liquids extraction EJ[scenarios])/Liquids extraction EJ

[scenarios]

Units: Dmnl

If=1, demand=supply. If>1, demand>supply. If<0, demand<supply.

Variable to avoid energy oversupply caused by exogenously driven

policies.

check liquids delayed 1yr[scenarios]= DELAY FIXED (

check liquids[scenarios], 1, 1)

Units: Dmnl

Variable to avoid energy oversupply caused by exogenously driven

policies.

choose extraction curve conv oil[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'D68')

choose extraction curve conv oil[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'D68')

choose extraction curve conv oil[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'D68')

choose extraction curve conv oil[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'D68')

choose extraction curve conv oil[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'D68')

choose extraction curve conv oil[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'D68')

Units: Dmnl

1= Maggio12 middle 2= Maggio12 High 3= Maggio12 Low 4= User defined

choose extraction curve total oil[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'D76')

choose extraction curve total oil[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'D76')

choose extraction curve total oil[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'D76')

choose extraction curve total oil[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'D76')

choose extraction curve total oil[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'D76')

choose extraction curve total oil[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'D76')

Units: Dmnl

1-Laherrère12 2-User defined

choose extraction curve unconv oil[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'D72')

choose extraction curve unconv oil[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'D72')

choose extraction curve unconv oil[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'D72')

choose extraction curve unconv oil[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'D72')

choose extraction curve unconv oil[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'D72')

choose extraction curve unconv oil[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'D72')

Units: Dmnl

1=BG Mohr15 2=Low Mohr15 3=Hihg Mohr15 4=User defined

"constrain liquids exogenous growth? delayed 1yr"[scenarios]= DELAY FIXED (

"constrain liquids exogenous growth?"[scenarios], 1, 1)

Units: Dmnl

"constrain liquids exogenous growth?"[scenarios]=

IF THEN ELSE(check liquids[scenarios]>0 ,1 ,check liquids[scenarios])

Units: Dmnl

If negative, there is oversupply of liquids. This variable is

used to constrain the exogenous growth of exogenously-driven

policies.

"CTL+GTL production EJ"[scenarios]=

CTL production[scenarios]+GTL production[scenarios]

Units: EJ/Year

CTL and GTL production.

cumulated conv oil extraction[scenarios]= INTEG (

extraction conv oil EJ[scenarios],

cumulated conv oil extraction to 1990)

Units: EJ

Cumulated conventional oil extraction.

cumulated conv oil extraction to 1990=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C94')

Units: EJ

Cumulated conventional oil extraction to 1990.

cumulated unconv oil extraction[scenarios]= INTEG (

extraction unconv oil EJ[scenarios],

cumulated unconv oil extraction to 1990)

Units: EJ

Cumulated unconventional oil extracted.

cumulated unconv oil extraction to 1990=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C95')

Units: EJ

Cumulated unconventional oil extraction to 1990.

Demand conv oil EJ[scenarios]=

MAX(Total demand liquids EJ[scenarios]-Other liquids extraction EJ[scenarios

]-extraction unconv oil EJ[scenarios], 0)

Units: EJ/Year

Demand of conventional oil. It is assumed that conventional oil

covers the rest of the liquids demand after accounting for the

contributions from other liquids and unconventional oil.

diff[scenarios]=

Demand conv oil EJ[scenarios]-extraction conv oil EJ[scenarios]

Units: **undefined**

efficiency liquids for electricity=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C45')

Units: Dmnl

Efficiency of oil in electricity power centrals. Stable trend

between 1971 and 2014 (IEA Balances), average of the period.

EJ per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C5')

Units: EJ/TWh

Unit conversion (3.6 EJ=1000 TWh)

extraction conv oil EJ[scenarios]=

MIN(Demand conv oil EJ[scenarios], max extraction conv oil EJ[scenarios])

Units: EJ/Year

Annual extraction of conventional oil.

extraction conv oil EJ delayed[scenarios]= DELAY FIXED (

extraction conv oil EJ[scenarios], 0.1, 128.5)

Units: EJ/Year

Conventional oil extraction delayed.

"extraction conv oil Mb/d"[scenarios]=

extraction conv oil EJ[scenarios]*"Mb/d per EJ/year"

Units: Mb/d

Annual extraction of conventional oil.

extraction conv oil Mtoe[scenarios]=

extraction conv oil EJ[scenarios]*MToe per EJ

Units: MToe/Year

Annual extraction of unconventional oil.

extraction unconv oil delayed[scenarios]= DELAY FIXED (

extraction unconv oil EJ[scenarios], 1, 1.09

)

Units: EJ/Year

Extraction of unconventional oil delayed 1 year. Data from Mohr
et al (2015) for 1989.

extraction unconv oil EJ[scenarios]=

IF THEN ELSE(Time<2013, Historic unconv oil, IF THEN ELSE("separate conv and unconv oil?"
[scenarios]=1, MIN(max extraction unconv oil[scenarios], max unconv oil growth extraction EJ
[scenarios]), 0))

Units: EJ/Year

Annual extraction of unconventional oil.

"extraction unconv oil Mb/d"[scenarios]=

extraction unconv oil EJ[scenarios]*"Mb/d per EJ/year"

Units: Mb/d

Annual extraction of unconventional oil.

extraction unconv oil Mtoe[scenarios]=

extraction unconv oil EJ[scenarios]*MToe per EJ

Units: MToe/Year

Annual extraction of unconventional oil.

FE Elec generation from total oil TWh[scenarios]=

Liquids extraction EJ[scenarios]*"share liquids/sector for Elec"[scenarios
]*efficiency liquids for electricity/EJ per TWh

Units: TWh/Year

Electricity generation (final energy) from total oil.

Gboe per EJ=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C18')

Units: EJ/Gboe

Unit conversion (1 EJ = 5.582 Gb).

Historic unconv oil:INTERPOLATE::=

GET XLS DATA('inputs.xlsx', 'Constants', '25' , 'C34')

Units: EJ/Year

Historic unconventional extraction from Mohr et al (2015).

Liquids extraction EJ[scenarios]=

total oil extraction EJ[scenarios]+Other liquids extraction EJ[scenarios]

Units: EJ/Year

Total liquids extraction.

Liquids extraction Mtoe[scenarios]=

Liquids extraction EJ[scenarios]*MToe per EJ

Units: MToe/Year

Total liquids extraction.

Liquids production for IB EJ[scenarios]=

Liquids extraction EJ[scenarios]*share liquids for IB[scenarios]

Units: EJ/Year

Annual liquids production for Industrial&Buildings sector.

max extraction conv oil EJ[scenarios]=

IF THEN ELSE("separate conv and unconv oil?"[scenarios]=1, IF THEN ELSE(choose extraction curve conv oil [scenarios]=1,

table max extraction Maggio12middle conv oil EJ(

RURR conv oil[scenarios]), IF THEN ELSE(choose extraction curve conv oil[scenarios]=2, table max extraction Maggio12 High conv oil EJ

(RURR conv oil[scenarios]), IF THEN ELSE(choose extraction curve conv oil[scenarios]=3, table max extraction Maggio12 Low con oil EJ(RURR conv oil[scenarios]), table max conv oil extraction User defined(RURR conv oil[scenarios

])))), IF THEN ELSE(choose extraction curve total oil[scenarios]=1, table max extraction Laherrère 2006 (

RURR conv oil[scenarios]), table max extraction total oil User defined(

RURR conv oil[scenarios])))

Units: EJ/Year

Maximum extraction curve selected for the simulations.

Max extraction conv oil Mtoe[scenarios]=

max extraction conv oil EJ[scenarios]*MToe per EJ

Units: MToe/Year

Maximum extraction curve selected for the simulations.

max extraction unconv oil[scenarios]=

IF THEN ELSE(choose extraction curve unconv oil[scenarios]=1, table max extraction unconv oil BG Mohr15 (RURR unconv oil EJ

[scenarios]), IF THEN ELSE(choose extraction curve unconv oil[scenarios]=2

, table max extraction unconv oil Low Mohr15(RURR unconv oil EJ[scenarios])

,IF THEN ELSE(choose extraction curve unconv oil[scenarios]=3, table max extraction unconv oil High Mohr15 (RURR unconv oil EJ[scenarios

]), table max extraction unconv oil User defined(RURR unconv oil EJ[scenarios

]))))

Units: EJ/Year

Maximum extraction curve selected for the simulations.

max unconv oil growth extraction[scenarios]=

1+IF THEN ELSE(Selection constraint extraction unconv oil[scenarios]=1,(P constraint growth extraction unconv oil

[scenarios]),("User-defined extraction growth unconv oil"(Time)))

Units: Dmnl

Constraint to maximum annual unconventional gas extraction (%).

max unconv oil growth extraction EJ[scenarios]=

IF THEN ELSE(check liquids delayed 1yr[scenarios]<-0.01, (1+"constrain liquids exogenous growth? delayed 1yr"

[scenarios])*extraction unconv oil delayed[scenarios],

extraction unconv oil delayed[scenarios]*max unconv oil growth extraction[

scenarios])

Units: EJ/Year

Constrained unconventional oil extraction growth (EJ/Year), i.e.

maximum annual growth compatible with the constraint selected in

the scenario.

"Mb/d per EJ/year"=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C17')

Units: Mb*Year/(EJ*d)

Conversion between Mb/d to EJ/year.

MToe per EJ=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C6')

Units: MToe/EJ

Unit conversion (1000 Mtoe=41.868 EJ)

Oil liquids saved by biofuels EJ[scenarios]=

PEavail total biofuels production EJ[scenarios]

Units: EJ/Year

Oil liquids saved by biofuels.

Oil refinery gains EJ[scenarios]=

Oil refinery gains share*extraction conv oil EJ delayed[scenarios]

Units: EJ/Year

Oil refinery gains.

Oil refinery gains share=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C74')

Units: Dmnl

We assume these energy gains are reached by applying natural gas

as energy input. Historically, their share has been growing in

the last decades (1.9% in 1980). WEO (2010) gives a 2.8% for the

year 2009 and BP (2007) 2.6%. The value 2.7% is taken.

Other liquids extraction EJ[scenarios]=

Oil refinery gains EJ[scenarios]+"CTL+GTL production EJ"[scenarios]+PEavail total biofuels production EJ [scenarios]

Units: EJ/Year

Other liquids refer to: refinery gains, CTL, GTL and biofuels.

P constraint growth extraction unconv oil[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C80')

P constraint growth extraction unconv oil[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C80')

P constraint growth extraction unconv oil[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C80')

P constraint growth extraction unconv oil[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C80')

P constraint growth extraction unconv oil[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C80')

P constraint growth extraction unconv oil[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C80')

Units: Dmnl

Constant constraint to annual extraction of unconventional oil.

PE demand liquids for Buildings EJ[scenarios]=

PE demand FF Buildings[scenarios]*"share incr liquids/FF for Build"[scenarios

]/tot shares incr Build[scenarios]

Units: EJ/Year

Primary energy demand of oil of the Buildings sector.

PE demand liquids for Elec EJ[scenarios]=

(FE demand liquids for Elec TWh[scenarios]/efficiency liquids for electricity

)*EJ per TWh

Units: EJ/Year

Primary energy demand of oil (EJ) for electric generation

(including generation losses).

PE demand liquids for Industry EJ[scenarios]=

PE demand FF Industry[scenarios]*"share incr liquids/FF for Ind"[scenarios

]/tot shares incr Ind[scenarios]

Units: EJ/Year

Primary energy demand of oil of the Industry sector.

PE liquids production for Transp EJ[scenarios]=

Liquids extraction EJ[scenarios]*share liquids for Transp[scenarios]

Units: EJ/Year

Total liquids produced for covering the energy requirements of

the Transportation sector.

PE losses oil for Elec EJ[scenarios]=

Liquids extraction EJ[scenarios]*"share liquids/sector for Elec"[scenarios

]*(1-efficiency liquids for electricity)

Units: EJ/Year

Primary energy losses related with oil for electricity
generation.

PEavail total biofuels production EJ[scenarios]=

PEavail biofuels 2gen land compet EJ[scenarios]+PEavail biofuels land marg EJ [scenarios]+PEavail biofuels prod 3gen EJ[scenarios]+PEavail cellulosic biofuel EJ [scenarios]

Units: EJ/Year

Final energy total biofuels production.

real PE demand of liquids for Transp EJ[scenarios]=

MAX(Liquid demand transp initial EJ[scenarios]-Oil liquids saved by EVs EJ [scenarios]-Oil liquids saved by NGVs[scenarios],0)

Units: EJ/Year

Energy demand in form of liquids of Transportation sector after
applying policies and technological shift.

RURR conv oil[scenarios]= INTEG (

-extraction conv oil EJ[scenarios],

URR conv oil[scenarios]-cumulated conv oil extraction to 1990)

Units: EJ

RURR conventional oil.

RURR unconv oil EJ[scenarios]= INTEG (

-extraction unconv oil EJ[scenarios],

URR unconv oil[scenarios]-cumulated unconv oil extraction to 1990)

Units: EJ

RURR unconventional oil.

Selection constraint extraction unconv oil[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'D80')

Selection constraint extraction unconv oil[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'D80')

Selection constraint extraction unconv oil[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'D80')

Selection constraint extraction unconv oil[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'D80')

Selection constraint extraction unconv oil[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'D80')

Selection constraint extraction unconv oil[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'D80')

Units: Dmnl

Selection of type of constraint to annual growth extraction of unconventional oil: 1= Constraint annual growth (%) 2= User defined as a function of time

"separate conv and unconv oil?"[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C67')

"separate conv and unconv oil?"[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C67')

"separate conv and unconv oil?"[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C67')

"separate conv and unconv oil?"[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C67')

"separate conv and unconv oil?"[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C67')

"separate conv and unconv oil?"[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C67')

Units: Dmnl

Switch to disaggregate between conventional and unconventional fuel: "1" = disaggregation, "0" = conv+unconv aggregated (all the oil flows then through the right side of this view, i.e. the "conventional oil" modelling side).

share liquids for IB[scenarios]=

1-"share liquids/sector for Elec"[scenarios]-share liquids for Transp[scenarios
]

Units: Dmnl

Share of liquids to cover energy consumption in the Industry & Buildings sector.

share liquids for Transp[scenarios]=

IF THEN ELSE(Total demand liquids EJ[scenarios]>0, real PE demand of liquids for Transp EJ [scenarios]/Total demand liquids EJ[scenarios],0)

Units: Dmnl

Share of liquids for Transportation. Condition to avoid error when the total demand of liquids falls to zero (0.5 is an arbitrary value).

"share liquids/sector for Elec"[scenarios]=

IF THEN ELSE(Total demand liquids EJ[scenarios]>0, PE demand liquids for Elec EJ [scenarios]/Total demand liquids EJ[scenarios], 0.5)

Units: Dmnl

Share of liquids to cover electricity consumption. Condition to avoid error when the total demand of liquids falls to zero (0.5 is an arbitrary value).

table max conv oil extraction User defined(

GET XLS LOOKUPS('inputs.xlsx', 'User defined', '139', 'D140'))

Units: EJ/Year

table max extraction ASPO oil EJ[scenarios](

[(0,0)-(13200,200)],(0,0),(600,29.9783),(1200,46.7403),(1800,59.4953),(2400 ,71.3603),(3000,84.9357),(3600,96.0997),(4200,107.465),(4800,118.46),(5400, 127.537),(6000,137.018),(6600,145.888),(7200,152.005),(7800,156.288),(8400, 162.47),(9000,166.659),(9600,171.044),(10200,171.044),(10800,171.044),(11400 ,171.044),(12000,171.044),(12600,171.044),(13200,171.044))

Units: EJ/Year

Curva ASPO de extracción de oil hasta 2050. Unidades: EJ. Para los puntos a partir del 2050 se ha realizado una exponencial negativa hasta anular las reservas en 2100. /*Considera crude y unconvencional oil, así que una vez separado no vale esta tabla*/

table max extraction Laherrère 2006=

GET XLS LOOKUPS('inputs.xlsx', 'Constants', '138' , 'D139')

Units: **undefined**

table max extraction Maggio12 High conv oil EJ(

GET XLS LOOKUPS('inputs.xlsx', 'Constants', '130' , 'D131'))

Units: EJ/Year

[Maggio2012]. Oil conventional+NGLs. High scenario con URR=3000 Gb.

table max extraction Maggio12 Low con oil EJ=

GET XLS LOOKUPS('inputs.xlsx', 'Constants', '126' , 'D127')

Units: **undefined**

table max extraction Maggio12middle conv oil EJ(

GET XLS LOOKUPS('inputs.xlsx', 'Constants', '128' , 'D129'))

Units: EJ/Year

[Maggio2012]. Oil conventional+NGLs. Scenario con URR=2600 Gb.(Middle scenario)

table max extraction total oil User defined=

GET XLS LOOKUPS('inputs.xlsx', 'User defined', '143', 'D144')

Units: **undefined**

table max extraction unconv oil BG Mohr15(

GET XLS LOOKUPS('inputs.xlsx', 'Constants', '132' , 'D133'))

Units: EJ/Year

table max extraction unconv oil High Mohr15(

GET XLS LOOKUPS('inputs.xlsx', 'Constants', '134' , 'D135'))

Units: EJ/Year

table max extraction unconv oil Low Mohr15(

GET XLS LOOKUPS('inputs.xlsx', 'Constants', '136' , 'D137'))

Units: EJ/Year

table max extraction unconv oil User defined(

GET XLS LOOKUPS('inputs.xlsx', 'User defined', '141', 'D142'))

Units: EJ/Year

TIME STEP = 0.25

Units: Year [0,?]

The time step for the simulation.

Total demand liquids EJ[scenarios]=

PE demand liquids for Elec EJ[scenarios]+PE demand liquids for Industry EJ [scenarios]+PE demand liquids for Buildings EJ[scenarios]+real PE demand of liquids for Transp EJ [scenarios]

Units: EJ/Year

Total demand of liquids.

"Total demand liquids mb/d"[scenarios]=

Total demand liquids EJ[scenarios]*"Mb/d per EJ/year"

Units: Mb/d

Total demand of liquids.

Total demand oil EJ[scenarios]=

Total demand liquids EJ[scenarios]-Other liquids extraction EJ[scenarios]

Units: EJ/Year

Total oil (conventional and unconventional) demand .

total oil extraction EJ[scenarios]=

extraction conv oil EJ[scenarios]+extraction unconv oil EJ[scenarios]

Units: EJ/Year

Total oil (conventional + unconventional) extraction.

total oil extraction Gb[scenarios]=

total oil extraction EJ[scenarios]*Gboe per EJ

Units: **undefined**

Total oil (conventional + unconventional) extraction.

total oil extraction Mtoe[scenarios]=

total oil extraction EJ[scenarios]*MToe per EJ

Units: **undefined**

Total oil (conventional + unconventional) extraction.

URR conv oil[scenarios]=

IF THEN ELSE("separate conv and unconv oil?"[scenarios]=1, IF THEN ELSE(choose extraction curve conv oil [scenarios]=1, URR conv oil Maggio12 middle, IF THEN ELSE(choose extraction curve conv oil

[scenarios]=2, URR conv oil Maggio12 High,IF THEN ELSE(choose extraction curve conv oil

[scenarios]=3, URR conv oil Maggio12 Low, URR conv oil User defined))) , IF THEN ELSE

(choose extraction curve total oil

[scenarios]=1, URR total oil Laherrère 2006, URR total oil User defined))

Units: EJ

Ultimately Recoverable Resources (URR) associated to the

selected depletion curve.

URR conv oil Maggio12 High=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'B130')

Units: EJ

[Maggio2012]. Oil conventional+NGLs. High scenario con URR=3000

Gb.

URR conv oil Maggio12 Low=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'B126')

Units: **undefined**

URR conv oil Maggio12 middle=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'B128')

Units: EJ

[Maggio2012]. Oil conventional+NGLs. Scenario con URR=2600

Gb.(Middle scenario)

URR conv oil User defined=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'B139')

Units: EJ

URR oil ASPO[scenarios]=

12800

Units: EJ

URR total oil Laherrère 2006=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'B138')

Units: **undefined**

URR total oil User defined=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'B143')

Units: **undefined**

URR unconv oil[scenarios]=

IF THEN ELSE(choose extraction curve unconv oil[scenarios]=1, URR unconv oil BG Mohr15

, IF THEN ELSE(choose extraction curve unconv oil

[scenarios]=2, URR unconv oil Low Mohr15, IF THEN ELSE(choose extraction curve unconv oil

[scenarios]=3, URR unconv oil Hihg Mohr15, URR unconv oil User defined)))

Units: EJ

URR unconv oil BG Mohr15=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'B132')

Units: EJ

URR unconv oil Hihg Mohr15=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'B134')

Units: EJ

URR unconv oil Low Mohr15=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'B136')

Units: EJ

URR unconv oil User defined=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'B141')

Units: EJ

"User-defined extraction growth unconv oil"(

GET XLS LOOKUPS('inputs.xlsx', 'User defined', '161', 'D162')

)

Units: Dmnl

User-defined annual extraction growth constraint path as a

function of time for unconventional oil.

Year scarcity liquids[scenarios]=

IF THEN ELSE(abundance liquids[scenarios]>0.95, 0, Time)

Units: Year

Year when the parameter abundance falls below 0.95, i.e. year
when scarcity starts.

Year scarcity oil[scenarios]=
IF THEN ELSE(abundance total oil[scenarios]>0.95, 0, Time)
Units: **undefined**
Year when the parameter abundance falls below 0.95, i.e. year
when scarcity starts.

30. RESOURCES – Gas extraction

abundance gas[scenarios]=
IF THEN ELSE(Total demand gas EJ[scenarios]<total gas extraction EJ[scenarios
], 1, 1-(Total demand gas EJ[scenarios]-total gas extraction EJ[scenarios]
)/Total demand gas EJ[scenarios])
Units: Dmnl
The parameter abundance varies between (1;0). Abundance=1 while
the supply covers the demand; the closest to 0 indicates a
higher divergence between supply and demand.

check gas[scenarios]=
(Total demand gas EJ[scenarios]-total gas extraction EJ[scenarios])/total gas extraction EJ
[scenarios]
Units: Dmnl
Variable to avoid energy oversupply caused by exogenously driven
policies.

check gas delayed 1yr[scenarios]= DELAY FIXED (
check gas[scenarios], 1, 1)
Units: Dmnl
Variable to avoid energy oversupply caused by exogenously driven
policies.

choose extraction conv gas curve[BAU]=
GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'D84')
choose extraction conv gas curve[SCEN1]=
GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'D84')

choose extraction conv gas curve[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'D84')

choose extraction conv gas curve[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'D84')

choose extraction conv gas curve[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'D84')

choose extraction conv gas curve[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'D84')

Units: Dmnl

1- BG Mohr15 2- Low Mohr15 3- High Mohr15 4- User defined

choose extraction curve unconv gas[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'D88')

choose extraction curve unconv gas[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'D88')

choose extraction curve unconv gas[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'D88')

choose extraction curve unconv gas[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'D88')

choose extraction curve unconv gas[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'D88')

choose extraction curve unconv gas[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'D88')

Units: Dmnl

1= BG Mohr15 2= Low Mohr15 3= High Mohr15

choose extraction total gas curve[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'D92')

choose extraction total gas curve[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'D92')

choose extraction total gas curve[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'D92')

choose extraction total gas curve[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'D92')

choose extraction total gas curve[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'D92')

choose extraction total gas curve[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'D92')

Units: Dmnl

1- Laherrère10 2- BG Mohr12 3- User defined

"constrain gas exogenous growth? delayed 1yr"[scenarios]= DELAY FIXED (

"constrain gas exogenous growth?"[scenarios], 1, 1)

Units: Dmnl

"constrain gas exogenous growth?"[scenarios]=

IF THEN ELSE(check gas[scenarios]>-0.01 ,1 ,check gas[scenarios])

Units: Dmnl

If negative, there is oversupply of gas. This variable is used

to constrain the exogenous growth of exogenously-driven policies.

cumulated conv gas extraction[scenarios]= INTEG (

extraction conv gas EJ[scenarios],

cumulated conv gas extraction to 1990)

Units: EJ

Cumulated conventional gas extraction.

cumulated conv gas extraction to 1990=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C96')

Units: EJ

Cumulated conventional gas extraction to 1990.

Cumulated unconv gas extraction[scenarios]= INTEG (

extraction unconv gas EJ[scenarios],

cumulated unconv gas extraction to 1990)

Units: EJ

Cumulated unconventional gas extraction.

cumulated unconv gas extraction to 1990=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C97')

Units: EJ

Cumulated unconventional gas extraction to 1990.

Demand conv gas[scenarios]=

MAX(Total demand gas EJ[scenarios]-extraction unconv gas EJ[scenarios], 0)

Units: EJ/Year

Demand of conventional gas. It is assumed that conventional gas

covers the rest of the liquids demand after accounting for the

contributions from unconventional gas.

demand gas for GTL EJ[scenarios]=

GTL production[scenarios]/GTL efficiency

Units: EJ/Year

Demand of gas for CTL.

demand gas for oil refinery gains[scenarios]=

Oil refinery gains EJ[scenarios]*Efficiency gas for oil refinery gains

Units: EJ/Year

Demand of natural gas to be used as input in the refineries to

obtain the so-called "oil refinery gains".

demand gas for Transp EJ[scenarios]=

PE demand for Transport initial EJ[scenarios]*propor gas transp losses+Oil liquids saved by NGVs [scenarios]

Units: EJ/Year

Energy demand in form of gas of Transportation.

efficiency gas for electricity= INTEG (

improvement efficiency gas for electricity,

initial efficiency gas for electricity)

Units: Dmnl

Efficiency of the gas power centrals.

Efficiency gas for oil refinery gains=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C51')

Units: Dmnl

We assume a 100% efficiency as first approximation.

EJ per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C5')

Units: EJ/TWh

Unit conversion (3.6 EJ=1000 TWh)

extraction conv gas EJ[scenarios]=

MIN(Demand conv gas[scenarios], max extraction conv gas EJ[scenarios])

Units: EJ/Year

Annual extraction of conventional gas.

extraction conv gas for GTL EJ[scenarios]=

demand gas for GTL EJ[scenarios]

Units: EJ/Year

Extraction of conventional gas for GTL. GTL demand is given priority over other uses of since it is an exogenous assumption depending on the scenario.

extraction conv gas without GTL EJ[scenarios]=

MAX(extraction conv gas EJ[scenarios]-extraction conv gas for GTL EJ[scenarios
], 0)

Units: EJ

Extraction of conventional gas excepting the resource used to produce GTL.

extraction conv gas without GTL Mtoe[scenarios]=

extraction conv gas without GTL EJ[scenarios]*MToe per EJ

Units: MToe/Year

Extraction of conventional gas excepting the resource used to produce GTL (Mtoe).

extraction unconv gas delayed[scenarios]=

DELAY FIXED(extraction unconv gas EJ[scenarios], 1, 0)

Units: EJ/Year

extraction unconv gas EJ[scenarios]=

IF THEN ELSE(Time<2013, Historic unconv gas, IF THEN ELSE("separate conv and unconv gas?"
[scenarios]=1, MIN(max extraction unconv gas[scenarios],max unconv gas growth extraction EJ
[scenarios]), 0))

Units: EJ/Year

Annual extraction of unconventional gas. IF THEN ELSE("separate conv and unconv gas?"[scenarios]=1, IF THEN ELSE(Time<2011, Historic unconv gas[scenarios](Time), MIN(max extraction unconv gas[scenarios],max unconv gas growth extraction EJ [scenarios])), 0)

extraction unconv gas Mtoe[scenarios]=

extraction unconv gas EJ[scenarios]*MToe per EJ

Units: MToe/Year

FE Elec generation from conv gas TWh[scenarios]=

extraction conv gas without GTL EJ[scenarios]*"share gas/sector for Elec"[scenarios]*efficiency gas for electricity/EJ per TWh

Units: TWh/Year

Final energy electricity generation from conventional gas (TWh).

FE Elec generation from unconv gas TWh[scenarios]=

extraction unconv gas EJ[scenarios]*"share gas/sector for Elec"[scenarios] *efficiency gas for electricity/EJ per TWh

Units: TWh/Year

Final energy electricity generation from unconventional gas (TWh).

GtCO2 per Mtoe conv gas=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C92')

Units: GTCO2e/MToe

2.35 tCO2/toe [BP2012] y [Farrell and Brandt, 2006]

Historic unconv gas:INTERPOLATE::=

GET XLS DATA('inputs.xlsx', 'Constants', '25' , 'C35')

Units: EJ/Year

Historic unconventional extraction from Mohr et al (2015).

max extraction conv gas EJ[scenarios]=

IF THEN ELSE("separate conv and unconv gas?"[scenarios]=1, IF THEN ELSE(choose extraction conv gas curve [scenarios]=1, table max extraction conv gas BG Mohr15(RURR conv gas [scenarios]), IF THEN ELSE(choose extraction conv gas curve[scenarios]=2, table max extraction conv gas Low Mohr15(RURR conv gas [scenarios]), IF THEN ELSE(choose extraction conv gas curve[scenarios]=3,

table max extraction conv gas High Mohr15(RURR conv gas

[scenarios]), table max extraction conv gas User defined(RURR conv gas[scenarios

])))), IF THEN ELSE(choose extraction total gas curve[scenarios]=1, table max extraction total gas Laherrère10

(RURR conv gas

[scenarios]), IF THEN ELSE(choose extraction total gas curve[scenarios]=2,

table max extraction total gas BG Mohr12(RURR conv gas

[scenarios]), table max extraction total gas User defined(RURR conv gas

[scenarios]))))

Units: EJ/Year

Maximum extraction curve selected for the simulations.

max extraction conv gas Mtoe[scenarios]=

max extraction conv gas EJ[scenarios]*MToe per EJ

Units: MToe/Year

Maximum extraction curve selected for the simulations.

max extraction unconv gas[scenarios]=

IF THEN ELSE(choose extraction curve unconv gas[scenarios]=1, table max extraction unconv gas BG Mohr15

(RURR unconv gas

[scenarios]), IF THEN ELSE(choose extraction curve unconv gas[scenarios]

=2, table max extraction unconv gas Low Mohr15(RURR unconv gas[scenarios])

,IF THEN ELSE(choose extraction curve unconv gas[scenarios]=3, table max extraction unconv gas High Mohr15

(RURR unconv gas[scenarios]), table max extraction unconv gas User defined

(RURR unconv gas[scenarios]))))

Units: EJ/Year

Maximum extraction curve selected for the simulations.

max unconv gas growth extraction[scenarios]=

1+IF THEN ELSE(Selection constraint extraction unconv gas[scenarios]=1, (P constraint growth extraction unconv gas

[scenarios])

,("User-defined extraction growth unconv gas"(Time)))

Units: Dmnl

Constraint to maximum annual unconventional gas extraction (%).

max unconv gas growth extraction EJ[scenarios]=

IF THEN ELSE(check gas delayed 1yr[scenarios]<-0.01, (1+"constrain gas exogenous growth? delayed 1yr"[scenarios])*extraction unconv gas delayed[scenarios],

extraction unconv gas delayed[scenarios]*max unconv gas growth extraction[scenarios])

Units: EJ/Year

Constrained unconventional gas extraction growth (EJ/Year), i.e.

maximum annual growth compatible with the constraint selected in the scenario.

MToe per EJ=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C6')

Units: MToe/EJ

Unit conversion (1000 Mtoe=41.868 EJ)

Oil refinery gains EJ[scenarios]=

Oil refinery gains share*extraction conv oil EJ delayed[scenarios]

Units: EJ/Year

Oil refinery gains.

P constraint growth extraction unconv gas[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C96')

P constraint growth extraction unconv gas[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C96')

P constraint growth extraction unconv gas[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C96')

P constraint growth extraction unconv gas[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C96')

P constraint growth extraction unconv gas[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C96')

P constraint growth extraction unconv gas[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C96')

Units: Dmnl

Constant constraint to annual extraction of unconventional gas.

PE demand gas for Buildings EJ[scenarios]=

PE demand FF Buildings[scenarios]*"share incr gas/FF for Build"[scenarios]/tot shares incr Build[scenarios]

Units: EJ/Year

Primary energy demand of gas of the Buildings sector.

PE demand gas for Elec EJ[scenarios]=

(FE demand gas for Elec TWh[scenarios]/efficiency gas for electricity)*EJ per TWh

Units: EJ/Year

Primary energy demand of natural gas (EJ) for electricity

consumption (including generation losses).

PE demand gas for Industry EJ[scenarios]=

PE demand FF Industry[scenarios]*"share incr gas/FF for Ind"[scenarios]/tot shares incr Ind

[scenarios]

Units: EJ/Year

Primary energy demand of gas of the Industry sector.

PE gas extraction for Transp EJ[scenarios]=

total gas extraction without GTL[scenarios]*share gas for Transp[scenarios

]

Units: EJ/Year

Primary energy gas extraction (excluding GTL) for Transportation.

PE losses conv gas for Elec EJ[scenarios]=

extraction conv gas without GTL EJ[scenarios]*"share gas/sector for Elec"[

scenarios]*(1-efficiency gas for electricity)

Units: EJ/Year

(Primary) Energy losses in the generation of electricity in gas

power centrals.

PE losses uncon gas for Elec EJ[scenarios]=

extraction unconv gas EJ[scenarios]*"share gas/sector for Elec"[scenarios]

*(1-efficiency gas for electricity)

Units: EJ/Year

(Primary) Energy losses in the generation of electricity in gas

power centrals.

RURR conv gas[scenarios]= INTEG (

-extraction conv gas EJ[scenarios],

URR conv gas[scenarios]-cumulated conv gas extraction to 1990)

Units: EJ

RURR conventional oil. 1500 EJ extracted before 1990.

RURR unconv gas[scenarios]= INTEG (

-extraction unconv gas EJ[scenarios],

URR unconv gas[scenarios]-cumulated unconv gas extraction to 1990)

Units: EJ

RURR unconventional gas.

Selection constraint extraction unconv gas[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'D96')

Selection constraint extraction unconv gas[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'D96')

Selection constraint extraction unconv gas[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'D96')

Selection constraint extraction unconv gas[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'D96')

Selection constraint extraction unconv gas[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'D96')

Selection constraint extraction unconv gas[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'D96')

Units: Dmnl

Selection of type of constraint to annual growth extraction of

unconventional gas: 3? 1= Constraint annual growth (%) 2= User

defined as a function of time

"separate conv and unconv gas?"[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C83')

"separate conv and unconv gas?"[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C83')

"separate conv and unconv gas?"[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C83')

"separate conv and unconv gas?"[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C83')

"separate conv and unconv gas?"[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C83')

"separate conv and unconv gas?"[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C83')

Units: Dmnl

Switch to disaggregate between conventional and unconventional fuel: "1" = disaggregation, "0" = conv+unconv aggregated (all the gas flows then through the right side of this view, i.e. the "conventional gas" modelling side).

share gas for IB[scenarios]=

1-"share gas/sector for Elec"[scenarios]-share gas for Transp[scenarios]-share gas for oil refinery gains [scenarios]

Units: Dmnl

Share of gas to cover energy consumption of Industry and Buildings.

share gas for oil refinery gains[scenarios]=

IF THEN ELSE(Total demand gas without GTL[scenarios]>0, demand gas for oil refinery gains [scenarios]/Total demand gas without GTL[scenarios], 0.5)

Units: Dmnl

Share of gas to cover oil refinery gains. Condition to avoid error when the total demand of gas without GTL falls to zero (0.5 is an arbitrary value).

share gas for Transp[scenarios]=

IF THEN ELSE(Total demand gas without GTL[scenarios]>0, demand gas for Transp EJ [scenarios]/Total demand gas without GTL[scenarios], 0.5)

Units: Dmnl

Share of gas for Transportation. Condition to avoid error when the total demand of gas without GTL falls to zero (0.5 is an arbitrary value).

"share gas/sector for Elec"[scenarios]=

IF THEN ELSE(Total demand gas without GTL[scenarios]>0, PE demand gas for Elec EJ [scenarios]/Total demand gas without GTL[scenarios], 0.5)

Units: Dmnl

Share of gas to cover electricity consumption. Condition to avoid error when the total demand of gas without GTL falls to zero (0.5 is an arbitrary value).

table max extraction conv gas BG Mohr15(

GET XLS LOOKUPS('inputs.xlsx', 'Constants', '145' , 'D146'))

Units: EJ/Year

table max extraction conv gas High Mohr15=

GET XLS LOOKUPS('inputs.xlsx', 'Constants', '143' , 'D144')

Units: **undefined**

table max extraction conv gas Low Mohr15=

GET XLS LOOKUPS('inputs.xlsx', 'Constants', '141' , 'D142')

Units: **undefined**

table max extraction conv gas User defined(

GET XLS LOOKUPS('inputs.xlsx', 'User defined', '146', 'D147'))

Units: EJ/Year

table max extraction gas Laherrere2010[scenarios](

[(0,0)-(13000,175)],(0,0),(500,23.8621),(1000,44.631),(1500,62.3067),(2000,77.7729),(2500,93.8891),(3000,107.821),(3500,119.752),(4000,129.033),(4500,137.87),(5000,144.16),(5500,148.917),(6000,151.78),(6500,152.895),(7000,152.895),(7500,152.895),(8000,152.895),(8500,152.895),(9000,152.895),(9500,152.895),(10000,152.895),(10500,152.895),(11000,152.895),(11500,152.895),(12000,152.895),(12500,152.895),(13000,152.895))

Units: EJ/Year

Curva Laherrere2010 de extracción de gas hasta 2100. Unidades:

EJ. Para los puntos a partir del 2100 se ha realizado una exponencial negativa hasta anular las reservas en 2120.

table max extraction gas Mohr BG2012[scenarios](

[(0,0)-(20000,200)],(0,0),(1000,27.4739),(2000,42.1041),(3000,51.2745),(4000,58.1215),(5000,69.3726),(6000,79.5334),(7000,99.1636),(8000,115.575),(9000,128.798),(10000,138.387),(11000,147.465),(12000,150.753),(13000,157.008),(14000,159.247),(15000,159.247),(16000,159.247),(17000,159.247),(18000,159.247),(19000,159.247),(20000,159.247))

Units: EJ/Year

Curva MohrBG2012 de extracción de gas hasta 2100. Unidades: EJ.

table max extraction gas Mohr High2012[scenarios](
[(0,0)-(30000,200)],(0,0),(1500,36.4477),(3000,58.3656),(4500,72.8198),(6000
,98.5),(7500,130.439),(9000,159.979),(10500,177.268),(12000,190.383),(13500
,194.052),(15000,194.197),(16500,194.197),(18000,194.197),(19500,194.197),(
21000,194.197),(22500,194.197),(24000,194.197),(25500,194.197),(27000,194.197
),(28500,194.197))
Units: EJ/Year
Curva Mohr High case 2013 de extracción de gas hasta 2100.
Unidades: EJ.

table max extraction total gas BG Mohr12=
GET XLS LOOKUPS('inputs.xlsx', 'Constants', '155' , 'D156')
Units: **undefined**

table max extraction total gas Laherrère10=
GET XLS LOOKUPS('inputs.xlsx', 'Constants', '153' , 'D154')
Units: **undefined**

table max extraction total gas User defined=
GET XLS LOOKUPS('inputs.xlsx', 'User defined', '150', 'D151')
Units: **undefined**

table max extraction unconv gas BG Mohr15(
GET XLS LOOKUPS('inputs.xlsx', 'Constants', '147' , 'D148'))
Units: EJ/Year

table max extraction unconv gas High Mohr15(
GET XLS LOOKUPS('inputs.xlsx', 'Constants', '149' , 'D150'))
Units: EJ/Year

table max extraction unconv gas Low Mohr15(
GET XLS LOOKUPS('inputs.xlsx', 'Constants', '151' , 'D152'))
Units: EJ/Year

table max extraction unconv gas User defined(

GET XLS LOOKUPS('inputs.xlsx', 'User defined', '148', 'D149'))

Units: EJ/Year

TIME STEP = 0.25

Units: Year [0,?]

The time step for the simulation.

Total demand gas EJ[scenarios]=

demand gas for GTL EJ[scenarios]+Total demand gas without GTL[scenarios]

Units: EJ/Year

Total demand of natural gas (EJ).

Total demand gas without GTL[scenarios]=

PE demand gas for Buildings EJ[scenarios]+PE demand gas for Industry EJ[scenarios
]+demand gas for oil refinery gains[scenarios]+demand gas for Transp EJ[scenarios
]+PE demand gas for Elec EJ[scenarios]

Units: EJ/Year

Total demand of natural gas without GTL.

total gas extraction EJ[scenarios]=

extraction conv gas EJ[scenarios]+extraction unconv gas EJ[scenarios]

Units: EJ/Year

Total gas extraction for IB EJ[scenarios]=

total gas extraction without GTL[scenarios]*share gas for IB[scenarios]

Units: EJ/Year

Total gas extraction for the Industtry & Buildings sector.

total gas extraction without GTL[scenarios]=

extraction conv gas without GTL EJ[scenarios]+extraction unconv gas EJ[scenarios
]

Units: EJ/Year

Total extraction of conventional gas and unconventional (without
GTL).

URR conv gas[scenarios]=

IF THEN ELSE("separate conv and unconv gas?"[scenarios]=1, IF THEN ELSE(choose extraction conv gas curve [scenarios]=1, URR conv gas BG Mohr15,IF THEN ELSE(choose extraction conv gas curve

[scenarios]=2, URR conv gas Low Mohr15, IF THEN ELSE(choose extraction conv gas curve

[scenarios]=3, URR conv gas High Mohr15, URR conv gas User defined))), IF THEN ELSE

(choose extraction total gas curve[scenarios]=1, URR total gas Leherrère10

, IF THEN ELSE(choose extraction total gas curve[scenarios]=2, URR total gas Mohr12 BG

, URR total gas User defined)))

Units: EJ

Ultimately Recoverable Resources (URR) associated to the

selected depletion curve.

URR conv gas BG Mohr15=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'B145')

Units: EJ

URR conv gas High Mohr15=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'B143')

Units: **undefined**

URR conv gas Low Mohr15=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'B141')

Units: **undefined**

URR conv gas User defined=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'B146')

Units: EJ

URR gas Leherrere2010[scenarios]=

13600

Units: EJ

URR gas Mohr BG2012[scenarios]=

19900

Units: EJ

URR gas Mohr High2013[scenarios]=

28500

Units: EJ

URR total gas Leherrère10=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'B153')

Units: **undefined**

URR total gas Mohr12 BG=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'B155')

Units: **undefined**

URR total gas User defined=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'B150')

Units: **undefined**

URR unconv gas[scenarios]=

IF THEN ELSE(choose extraction curve unconv gas[scenarios]=1, URR unconv gas BG Mohr15

, IF THEN ELSE(choose extraction curve unconv gas

[scenarios]=2, URR unconv gas Low Mohr15,IF THEN ELSE(choose extraction curve unconv gas

[scenarios]=3, URR unconv gas High Mohr15, URR unconv gas User defined)))

Units: EJ

URR unconv gas BG Mohr15=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'B147')

Units: EJ

URR unconv gas High Mohr15=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'B149')

Units: EJ

URR unconv gas Low Mohr15=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'B151')

Units: EJ

URR unconv gas User defined=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'B148')

Units: EJ

"User-defined extraction growth unconv gas"(

GET XLS LOOKUPS('inputs.xlsx', 'User defined', '163', 'D164'))

Units: Dmnl

User-defined annual extraction growth constraint path as a function of time for unconventional gas.

Year scarcity gas[scenarios]=

IF THEN ELSE(abundance gas[scenarios]>0.95, 0, Time)

Units: Year

Year when the parameter abundance falls below 0.95, i.e. year when scarcity starts.

31. RESOURCES – Coal extraction

abundance coal[scenarios]=

IF THEN ELSE(extraction coal EJ[scenarios]>(Total demand coal EJ[scenarios]), 1, 1-(((Total demand coal EJ[scenarios])-extraction coal EJ[scenarios])/Total demand coal EJ[scenarios]))

Units: Dmnl

The parameter abundance varies between (1;0). Abundance=1 while the supply covers the demand; the closest to 0 indicates a higher divergence between supply and demand.

choose extraction coal curve[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'D100')

choose extraction coal curve[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'D100')

choose extraction coal curve[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'D100')

choose extraction coal curve[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'D100')

choose extraction coal curve[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'D100')

choose extraction coal curve[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'D100')

Units: Dmnl

1= Mohr12 2= Other

Cumulated coal extraction[scenarios]= INTEG (

extraction coal EJ[scenarios],

cumulated coal extraction to 1990)

Units: EJ

Cumulated coal extraction.

cumulated coal extraction to 1990=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C98')

Units: EJ

Cumulated coal extraction to 1990.

demand coal for CTL EJ[scenarios]=

CTL production[scenarios]/CTL efficiency

Units: EJ/Year

Demand of coal for CTL.

efficiency coal for electricity=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C46')

Units: Dmnl

Efficiency of coal gas power centrals. Stable trend between 1971 and 2014 (IEA Balances), average of the period.

EJ per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C5')

Units: EJ/TWh

Unit conversion (3.6 EJ=1000 TWh)

extraction coal EJ[scenarios]=

MIN(Total demand coal EJ[scenarios], max extraction coal EJ[scenarios])

Units: EJ/Year

Annual extraction of coal.

extraction coal for CTL EJ[scenarios]=

demand coal for CTL EJ[scenarios]

Units: EJ/Year

Extraction of coal for CTL. CTL demand is given priority over other uses since it is an exogenous assumption depending on the scenario.

extraction coal Mtoe[scenarios]=

extraction coal EJ[scenarios]*MToe per EJ

Units: MToe/Year

Annual extraction of coal.

extraction coal without CTL EJ[scenarios]=

MAX(extraction coal EJ[scenarios]-extraction coal for CTL EJ[scenarios], 0

)

Units: EJ/Year

Extraction of conventional gas excepting the resource used to

produce GTL.

FE Elec generation from coal TWh[scenarios]=

extraction coal without CTL EJ[scenarios]*efficiency coal for electricity*

"share coal/sector for Elec"[scenarios]/EJ per TWh

Units: TWh/Year

Final energy electricity generation from coal (TWh).

max extraction coal EJ[scenarios]=

IF THEN ELSE(choose extraction coal curve[scenarios]=1, table max extraction coal Mohr2012 EJ

(RURR coal[

scenarios]), IF THEN ELSE(choose extraction coal curve[scenarios]=2, table max extraction coal Low Mohr15

(RURR coal[scenarios]), IF THEN ELSE(choose extraction coal curve[scenarios

]=3, table max extraction coal BG Mohr15(RURR coal[scenarios]), IF THEN ELSE

(choose extraction coal curve[scenarios]=4, table max extraction coal High Mohr15

(RURR coal[scenarios]), table max extraction coal User defined(RURR coal[scenarios

])))))

Units: EJ/Year

Maximum extraction curve selected for the simulations.

max extraction coal Mtoe[scenarios]=

max extraction coal EJ[scenarios]*MToe per EJ

Units: MToe/Year

Maximum extraction curve selected for the simulations.

MToe per EJ=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C6')

Units: MToe/EJ

Unit conversion (1000 Mtoe=41.868 EJ)

PE coal for IB EJ[scenarios]=

extraction coal without CTL EJ[scenarios]*share coal for IB[scenarios]

Units: EJ/Year

PE demand coal for Buildings EJ[scenarios]=

PE demand FF Buildings[scenarios]*"share incr coal/FF for Build"[scenarios
]/tot shares incr Build[scenarios]

Units: EJ/Year

Primary energy demand of coal of the Buildings sector.

PE demand coal for Elec EJ[scenarios]=

(FE demand coal for Elec TWh[scenarios]/efficiency coal for electricity)*EJ per TWh

Units: EJ/Year

Primary energy demand of coal (EJ) for electricity consumption
(including generation losses).

PE demand coal for Elec Mtoe[scenarios]=

PE demand coal for Elec EJ[scenarios]*MToe per EJ

Units: MToe/Year

Primary energy demand of coal (EJ) for electricity consumption.

PE demand coal for Industry EJ[scenarios]=

PE demand FF Industry[scenarios]*"share incr coal/FF for Ind"[scenarios]/tot shares incr Ind
[scenarios]

Units: EJ/Year

Primary energy demand of coal of the Industry sector.

PE losses coal for Elec EJ[scenarios]=

extraction coal without CTL EJ[scenarios]*"share coal/sector for Elec"[scenarios
]*(1-efficiency coal for electricity)

Units: EJ/Year

(Primary) Energy losses in the generation of electricity in coal power centrals.

RURR coal[scenarios]= INTEG (

-extraction coal EJ[scenarios],

URR coal[scenarios]-cumulated coal extraction to 1990)

Units: EJ

RURR coal. 4400 EJ extracted before 1990.

share coal for IB[scenarios]=

1-"share coal/sector for Elec"[scenarios]

Units: Dmnl

Share of coal to cover energy consumption of Industry and

Buildings.

"share coal/sector for Elec"[scenarios]=

IF THEN ELSE(Total demand coal without CTL[scenarios]>0, PE demand coal for Elec EJ

[scenarios]/Total demand coal without CTL[scenarios], 0.5)

Units: Dmnl

Share of coal (sector) to cover electricity consumption.

Condition to avoid error when the total demand of coal without

CTL falls to zero (0.5 is an arbitrary value).

table max extraction coal BG Mohr15(

GET XLS LOOKUPS('inputs.xlsx', 'Constants', '162' , 'D163'))

Units: **undefined**

table max extraction coal High Mohr15=

GET XLS LOOKUPS('inputs.xlsx', 'Constants', '164' , 'D165')

Units: **undefined**

table max extraction coal Low Mohr15=

GET XLS LOOKUPS('inputs.xlsx', 'Constants', '160' , 'D161')

Units: **undefined**

table max extraction coal Mohr2012 EJ(

GET XLS LOOKUPS('inputs.xlsx', 'Constants', '158' , 'D159'))

Units: EJ/Year

Curva [Mohr2012] High Case. update de [Mohr2009]

table max extraction coal User defined(
GET XLS LOOKUPS('inputs.xlsx', 'User defined', '153', 'D154'))
Units: EJ/Year

TIME STEP = 0.25
Units: Year [0,?]
The time step for the simulation.

Total demand coal EJ[scenarios]=
Total demand coal without CTL[scenarios]+demand coal for CTL EJ[scenarios]
Units: EJ/Year
Total demand of coal.

Total demand coal without CTL[scenarios]=
PE demand coal for Buildings EJ[scenarios]+PE demand coal for Industry EJ[
scenarios]+PE demand coal for Elec EJ[scenarios]
Units: **undefined**
Total demand of coal without CTL.

URR coal[scenarios]=
IF THEN ELSE(choose extraction coal curve[scenarios]=1, URR coal Mohr2012 EJ
, IF THEN ELSE(choose extraction coal curve[scenarios]=2, URR coal Low Mohr15
, IF THEN ELSE(choose extraction coal curve[scenarios]=3, URR coal BG Mohr15
, IF THEN ELSE(choose extraction coal curve[scenarios]=4, URR coal High15,
URR coal User defined EJ))))
Units: EJ
Ultimately Recoverable Resources (URR) associated to the
selected depletion curve.

URR coal BG Mohr15=
GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'B162')
Units: **undefined**

URR coal High15=
GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'B164')

Units: **undefined**

URR coal Low Mohr15=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'B160')

Units: **undefined**

URR coal Mohr2012 EJ=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'B158')

Units: EJ

URR coal User defined EJ=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'B153')

Units: EJ

Year scarcity coal[scenarios]=

IF THEN ELSE(abundance coal[scenarios]>0.95, 0, Time)

Units: Year

Year when the parameter abundance falls below 0.95, i.e. year

when scarcity starts.

32. RESOURCES – Uranium extraction

abundance uranium[scenarios]=

IF THEN ELSE(PE demand uranium EJ[scenarios]=0, 1, IF THEN ELSE(extraction uranium EJ

[scenarios]>PE demand uranium EJ[scenarios

], 1, 1-((PE demand uranium EJ[scenarios]-extraction uranium EJ[scenarios

])/PE demand uranium EJ[scenarios])))

Units: Dmnl

The parameter abundance varies between (1;0). Abundance=1 while

the supply covers the demand; the closest to 0 indicates a

higher divergence between supply and demand.

Choose extraction uranium curve[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'D105')

Choose extraction uranium curve[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'D105')

Choose extraction uranium curve[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'D105')

Choose extraction uranium curve[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'D105')

Choose extraction uranium curve[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'D105')

Choose extraction uranium curve[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'D105')

Units: Dmnl

1-EWG13 2-Other

Cumulated uranium extraction[scenarios]= INTEG (

extraction uranium EJ[scenarios],

cumulated uranium extraction to 1990)

Units: EJ

Cumulated uranium extraction.

Cumulated uranium extraction kt[scenarios]=

Cumulated uranium extraction[scenarios]*kt uranium per EJ

Units: Kt

Cumulated uranium extraction (kt).

cumulated uranium extraction to 1990=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C99')

Units: EJ

Cumulated coal extraction to 1990.

efficiency uranium for electricity=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C41')

Units: Dmnl

Efficiency of uranium in nuclear power centrals. [IEA Balances].

EJ per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C5')

Units: EJ/TWh

Unit conversion (3.6 EJ=1000 TWh)

Elec gen nuclear capacity available TWh[scenarios]=

Nuclear capacity GW[scenarios]*Cp nuclear[scenarios]/(TWe per TWh*1000)

Units: TWh/Year

Electricity generation compatible with the existing

infraestructure.

extraction uranium EJ[scenarios]=

MIN(MIN(PE demand uranium EJ[scenarios], max extraction uranium EJ[scenarios

]), PE Elec gen nuclear capacity available EJ[

scenarios])

Units: EJ/Year

Annual extraction of uranium.

extraction uranium kt[scenarios]=

extraction uranium EJ[scenarios]*kt uranium per EJ

Units: Kt/Year

Extracción of uranium in kt.

extraction uranium Mtoe[scenarios]=

extraction uranium EJ[scenarios]*MToe per EJ

Units: MToe/Year

Annual extraction of uranium (Mtoe).

FE nuclear Elec generation TWh[scenarios]=

extraction uranium EJ[scenarios]*efficiency uranium for electricity/EJ per TWh

Units: TWh/Year

Final energy electricity generation from uranium (TWh).

gCO2e per kWh nuclear=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'E15')

Units: gCO2e/kWh

9-70 gCO2e/kWh [Arvesen 2011]. (1 g/KWh = 0.001 Gt/TWh)

GtCO2e nuclear[scenarios]=

FE nuclear Elec generation TWh[scenarios]*gCO2e per kWh nuclear*GTCO2e per gCO2e

*kWh per TWh

Units: GTCO2e/Year

GTCO2e per gCO2e=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C8')

Units: GTCO2e/gCO2e

Conversion between GTCO2 and gCO2 (1 GT = 1e15 g).

kt uranium per EJ=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C10')

Units: Kt/EJ

Unit conversion (1 EJ thermal = 2.3866). See EWG (2006).

kWh per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C9')

Units: kWh/TWh

Conversion between kWh and TWh (1 TWh=1e9 kWh).

Liquids extraction EJ[scenarios]=

total oil extraction EJ[scenarios]+Other liquids extraction EJ[scenarios]

Units: EJ/Year

Total liquids extraction.

max extraction uranium EJ[scenarios]=

IF THEN ELSE(Choose extraction uranium curve[scenarios]=1, table max extraction uranium EWG13 EJ (RURR uranium[scenarios

]), IF THEN ELSE(Choose extraction uranium curve[scenarios]=2, table max extraction uranium Zittel12 (RURR uranium[scenarios]), table max extraction uranium user defined(RURR uranium [scenarios])))

Units: EJ/Year

Maximum extraction curve selected for the simulations.

MToe per EJ=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C6')

Units: MToe/EJ

Unit conversion (1000 Mtoe=41.868 EJ)

PE demand uranium EJ[scenarios]=

demand Nuclear TWh[scenarios]*EJ per TWh/efficiency uranium for electricity

Units: **undefined**

Primary energy demand of uranium for nuclear power generation.

PE Elec gen nuclear capacity available EJ[scenarios]=

Elec gen nuclear capacity available TWh[scenarios]*EJ per TWh/efficiency uranium for electricity

Units: EJ

PE losses uranium for Elec EJ[scenarios]=

extraction uranium EJ[scenarios]*(1-efficiency uranium for electricity)

Units: EJ/Year

(Primary) Energy losses in the generation of electricity in

nuclear power centrals.

RURR uranium[scenarios]= INTEG (

-extraction uranium EJ[scenarios],

URR uranium[scenarios]-cumulated uranium extraction to 1990)

Units: EJ

RURR uranium. 720 EJ extracted before 1990.

table max extraction uranium EWG13 EJ(

GET XLS LOOKUPS('inputs.xlsx', 'Constants', '169' , 'D170'))

Units: EJ/Year

[EWG2013]

table max extraction uranium user defined=

GET XLS LOOKUPS('inputs.xlsx', 'User defined', '156', 'D157')

Units: EJ/Year

table max extraction uranium Zittel12=

GET XLS LOOKUPS('inputs.xlsx', 'Constants', '167' , 'D168')

Units: **undefined**

Total demand liquids EJ[scenarios]=

PE demand liquids for Elec EJ[scenarios]+PE demand liquids for Industry EJ [scenarios]+PE demand liquids for Buildings EJ[scenarios]+real PE demand of liquids for Transp EJ [scenarios]

Units: EJ/Year

Total demand of liquids.

URR uranium[scenarios]=

IF THEN ELSE(Choose extraction uranium curve[scenarios]=1, URR uranium EWG13

, IF THEN ELSE(Choose extraction uranium curve[scenarios]=2, URR uranium Zittel12

, URR uranium User defined))

Units: EJ

Ultimately Recoverable Resources (URR) associated to the

selected depletion curve.

URR uranium EWG13=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'B169')

Units: EJ

3900 Según [EWG2013] (curvas_recursos.xlsx).

URR uranium User defined=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'B156')

Units: EJ

URR uranium Zittel12=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'B167')

Units: **undefined**

Year scarcity uranium[scenarios]=

IF THEN ELSE(abundance uranium[scenarios]>0.95, 0, Time)

Units: Year

Year when the parameter abundance falls below 0.95, i.e. year

when scarcity starts.

33. RESOURCES – CTL & GTL

abundance coal[scenarios]=

IF THEN ELSE(extraction coal EJ[scenarios]>(Total demand coal EJ[scenarios

]), 1, 1-(((Total demand coal EJ[scenarios])-extraction coal EJ[scenarios]

)/Total demand coal EJ[scenarios]))

Units: Dmnl

The parameter abundance varies between (1;0). Abundance=1 while

the supply covers the demand; the closest to 0 indicates a higher divergence between supply and demand.

abundance gas[scenarios]=

IF THEN ELSE(Total demand gas EJ[scenarios]<total gas extraction EJ[scenarios
], 1, 1-(Total demand gas EJ[scenarios]-total gas extraction EJ[scenarios])
/Total demand gas EJ[scenarios])

Units: Dmnl

The parameter abundance varies between (1;0). Abundance=1 while the supply covers the demand; the closest to 0 indicates a higher divergence between supply and demand.

abundance liquids[scenarios]=

IF THEN ELSE((Total demand liquids EJ[scenarios])<(Liquids extraction EJ[scenarios
]), 1, 1-((Total demand liquids EJ[scenarios]-Liquids extraction EJ[scenarios
])/Total demand liquids EJ[scenarios]))

Units: Dmnl

The parameter abundance varies between (1;0). Abundance=1 while the supply covers the demand; the closest to 0 indicates a higher divergence between supply and demand.

"abundance liquids CTL+GTL"[scenarios]=

SQRT(ABS((Total demand liquids EJ[scenarios]-"CTL+GTL production EJ"[scenarios
])/Total demand liquids EJ[scenarios]))

Units: Dmnl

Variable to moderate the growth of GTL and CTL when the come close to supply all the liquids.

"Additional PE production of CTL+GTL for liquids"[scenarios]=

demand coal for CTL EJ[scenarios]+demand gas for GTL EJ[scenarios]-"CTL+GTL production EJ"
[scenarios]

Units: EJ/Year

Additional primary energy production of CTL and GTL for liquids. We need to account for this difference since the oil replaced by CTL liquids is accounted for primary energy in WoLiM, while there are additional losses to process coal to obtain CTL (required to balance the TPES with the TPED).

check liquids[scenarios]=

(Total demand liquids EJ[scenarios]-Liquids extraction EJ[scenarios])/Liquids extraction EJ [scenarios]

Units: Dmnl

If=1, demand=supply. If>1, demand>supply. If<0, demand<supply.

Variable to avoid energy oversupply caused by exogenously driven policies.

"constrain liquids exogenous growth?"[scenarios]=

IF THEN ELSE(check liquids[scenarios]>0 ,1 ,check liquids[scenarios])

Units: Dmnl

If negative, there is oversupply of liquids. This variable is used to constrain the exogenous growth of exogenously-driven policies.

CTL efficiency=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C49')

Units: Dmnl

Efficiency of CTL plants. Source: IEA balances (see Technical Report).

CTL Gb[scenarios]=

CTL production[scenarios]/Gboe per EJ

Units: Gboe/Year

Annual CTL production (Gb).

CTL production[scenarios]= INTEG (

variation CTL[scenarios],

initial CTL production)

Units: EJ/Year

Annual CTL production.

"CTL+GTL Gb"[scenarios]=

"CTL+GTL production EJ"[scenarios]/Gboe per EJ

Units: Gboe/Year

CTL and GTL production.

"CTL+GTL Mtoe"[scenarios]=

"CTL+GTL production EJ"[scenarios]*MToe per EJ

Units: MToe

CTL and GTL production.

"CTL+GTL production EJ"[scenarios]=

CTL production[scenarios]+GTL production[scenarios]

Units: EJ/Year

CTL and GTL production.

demand coal for CTL EJ[scenarios]=

CTL production[scenarios]/CTL efficiency

Units: EJ/Year

Demand of coal for CTL.

demand gas for GTL EJ[scenarios]=

GTL production[scenarios]/GTL efficiency

Units: EJ/Year

Demand of gas for CTL.

effects shortage coal[scenarios]=

IF THEN ELSE(abundance coal[scenarios]>0.8, ((abundance coal[scenarios]-0.8

)*5)^2, 0)

Units: Dmnl

The eventual scarcity of coal would likely constrain the

development of CTL. The proposed relationship avoids an abrupt

limitation by introducing a range (1;0.8) in the gas abundance

that constrains the development of CTL.

effects shortage gas[scenarios]=

IF THEN ELSE(abundance gas[scenarios]>0.8, ((abundance gas[scenarios]-0.8)

*5)^2, 0)

Units: Dmnl

The eventual scarcity of gas would likely constrain the

development of NGVs/GTLs. The proposed relationship avoids an

abrupt limitation by introducing a range (1;0.8) in the gas

abundance that constrains the development of NGVs/GTLs.

Gboe per EJ=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C18')

Units: EJ/Gboe

Unit conversion (1 EJ = 5.582 Gb).

GTL efficiency=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C50')

Units: Dmnl

Efficiency of GTL plants. Source: IEA balances (see Technical Report).

GTL Gb[scenarios]=

GTL production[scenarios]/Gboe per EJ

Units: Gboe/Year

Annual GTL production (Gb).

GTL production[scenarios]= INTEG (

variation GTL[scenarios],

initial GTL production)

Units: EJ/Year

Annual GTL production.

Hist growth CTL=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C89')

Units: 1/Year

Historic growth of CTL 1990-2014 (IEA Balances).

Hist growth GTL=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C90')

Units: 1/Year

Historic growth of GTL 2000-2014 (IEA Balances).

Historic CTL production=

GET XLS LOOKUPS('inputs.xlsx', 'Constants', '25' , 'C36')

Units: EJ/Year

Historic generation of CTL 1990-2014 (IEA Balances).

Historic GTL production=

GET XLS LOOKUPS('inputs.xlsx', 'Constants', '25' , 'C37')

Units: EJ/Year

Historic generation of GTL 1990-2014 (IEA Balances).

initial CTL production=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C36')

Units: EJ/Year

Balances IEA

initial GTL production=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C37')

Units: EJ/Year

Balances IEA

MToe per EJ=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C6')

Units: MToe/EJ

Unit conversion (1000 Mtoe=41.868 EJ)

P CTL[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C110')

P CTL[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C110')

P CTL[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C110')

P CTL[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C110')

P CTL[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C110')

P CTL[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C110')

Units: 1/Year

Annual growth in energy output demand depending on the policy of the scenario.

P GTL[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C112')

P GTL[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C112')

P GTL[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C112')

P GTL[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C112')

P GTL[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C112')

P GTL[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C112')

Units: 1/Year

Annual growth in energy output demand depending on the policy of the scenario.

Policy CTL[scenarios]=

IF THEN ELSE(abundance liquids[scenarios]>0.95, Hist growth CTL, P CTL[scenarios
])

Units: 1/Year

If there is not scarcity of liquids, CTL production increases at historical past rates.

Policy GTL[scenarios]=

IF THEN ELSE(abundance liquids[scenarios]>0.95, Hist growth GTL, P GTL[scenarios
])

Units: 1/Year

If there is not scarcity of liquids, GTL production increases at historical past rates.

real growth CTL[scenarios]=

IF THEN ELSE(abundance coal[scenarios]>=abundance liquids[scenarios],Policy CTL
[scenarios]*effects shortage coal[scenarios
]*(1+(abundance coal[scenarios]-abundance liquids[scenarios])),0)*"abundance liquids CTL+GTL"
[scenarios]

Units: 1/Year

The real growth of CTL depends on the relative abundance of coal and liquids, as well as on the scarcity of coal.

real growth GTL[scenarios]=

IF THEN ELSE(abundance gas[scenarios]>=abundance liquids[scenarios],Policy GTL [scenarios]*effects shortage gas[scenarios]*(1+(abundance gas[scenarios]-abundance liquids[scenarios])),0)*"abundance liquids CTL+GTL" [scenarios]

Units: 1/Year

The real growth of GTL depends on the relative abundance of gas and liquids, as well as on the scarcity of gas.

Total demand liquids EJ[scenarios]=

PE demand liquids for Elec EJ[scenarios]+PE demand liquids for Industry EJ [scenarios]+PE demand liquids for Buildings EJ[scenarios]+real PE demand of liquids for Transp EJ [scenarios]

Units: EJ/Year

Total demand of liquids.

variation CTL[scenarios]=

IF THEN ELSE(Time<2013, Historic CTL production(Time+1)-Historic CTL production (Time),

IF THEN ELSE(check liquids[scenarios]<-0.01, "constrain liquids exogenous growth?" [scenarios]*CTL production[scenarios],

CTL production[scenarios]*real growth CTL[scenarios]))

Units: EJ/Year

New annual CTL production.

variation GTL[scenarios]=

IF THEN ELSE(Time<2013, Historic GTL production(Time+1)-Historic GTL production (Time),

IF THEN ELSE(check liquids[scenarios]<-0.01, "constrain liquids exogenous growth?" [scenarios]*GTL production[scenarios],

GTL production[scenarios]*real growth GTL[scenarios]))

Units: EJ/Year

New annual GTL production.

34. TPES

abundance TPE[scenarios]=

IF THEN ELSE(TPES EJ[scenarios]>TPED by sector EJ[scenarios], 1, 1-((TPED by sector EJ [scenarios]-TPES EJ[scenarios])/TPED by sector EJ[scenarios]))

Units: Dmnl

The parameter abundance varies between (1;0). Abundance=1 while the supply covers the demand; the closest to 0 indicates a higher divergence between supply and demand.

"CTL+GTL production EJ"[scenarios]=

CTL production[scenarios]+GTL production[scenarios]

Units: EJ/Year

CTL and GTL production.

extraction coal EJ[scenarios]=

MIN(Total demand coal EJ[scenarios], max extraction coal EJ[scenarios])

Units: EJ/Year

Annual extraction of coal.

extraction coal Mtoe[scenarios]=

extraction coal EJ[scenarios]*MToe per EJ

Units: MToe/Year

Annual extraction of coal.

extraction coal without CTL EJ[scenarios]=

MAX(extraction coal EJ[scenarios]-extraction coal for CTL EJ[scenarios], 0
)

Units: EJ/Year

Extraction of conventional gas excepting the resource used to produce GTL.

extraction conv gas without GTL EJ[scenarios]=

MAX(extraction conv gas EJ[scenarios]-extraction conv gas for GTL EJ[scenarios
], 0)

Units: EJ

Extraction of conventional gas excepting the resource used to produce GTL.

extraction conv gas without GTL Mtoe[scenarios]=

extraction conv gas without GTL EJ[scenarios]*MToe per EJ

Units: MToe/Year

Extraction of conventional gas excepting the resource used to produce GTL (Mtoe).

extraction conv oil EJ[scenarios]=

MIN(Demand conv oil EJ[scenarios], max extraction conv oil EJ[scenarios])

Units: EJ/Year

Annual extraction of conventional oil.

extraction conv oil Mtoe[scenarios]=

extraction conv oil EJ[scenarios]*MToe per EJ

Units: MToe/Year

Annual extraction of unconventional oil.

extraction unconv gas EJ[scenarios]=

IF THEN ELSE(Time<2013, Historic unconv gas, IF THEN ELSE("separate conv and unconv gas?"[scenarios]=1, MIN(max extraction unconv gas[scenarios],max unconv gas growth extraction EJ[scenarios]), 0))

Units: EJ/Year

Annual extraction of unconventional gas. IF THEN ELSE("separate conv and unconv gas?"[scenarios]=1, IF THEN ELSE(Time<2011, Historic unconv gas[scenarios](Time), MIN(max extraction unconv gas[scenarios],max unconv gas growth extraction EJ[scenarios])), 0)

extraction unconv gas Mtoe[scenarios]=

extraction unconv gas EJ[scenarios]*MToe per EJ

Units: MToe/Year

extraction unconv oil EJ[scenarios]=

IF THEN ELSE(Time<2013, Historic unconv oil, IF THEN ELSE("separate conv and unconv oil?"[scenarios]=1, MIN(max extraction unconv oil[scenarios], max unconv oil growth extraction EJ[scenarios]), 0))

Units: EJ/Year

Annual extraction of unconventional oil.

extraction unconv oil Mtoe[scenarios]=

extraction unconv oil EJ[scenarios]*MToe per EJ

Units: MToe/Year

Annual extraction of unconventional oil.

extraction uranium EJ[scenarios]=

MIN(MIN(PE demand uranium EJ[scenarios], max extraction uranium EJ[scenarios

]), PE Elec gen nuclear capacity available EJ[

scenarios])

Units: EJ/Year

Annual extraction of uranium.

extraction uranium Mtoe[scenarios]=

extraction uranium EJ[scenarios]*MToe per EJ

Units: MToe/Year

Annual extraction of uranium (Mtoe).

GDP[scenarios]=

GDPcap[scenarios]*Population[scenarios]/dollars to Tdollars

Units: Tdollars/Year

Global Domestic Product.

MToe per EJ=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C6')

Units: MToe/EJ

Unit conversion (1000 Mtoe=41.868 EJ)

real total energy Intensity EJ T$[scenarios]=

TPES EJ[scenarios]/GDP[scenarios]

Units: EJ/Tdollars

Total energy intensity

share RES vs TPES[scenarios]=

TPE from RES EJ[scenarios]/TPES EJ[scenarios]

Units: Dmnl

Share of primary energy from RES in the TPES.

TIME STEP = 0.25

Units: Year [0,?]

The time step for the simulation.

Total extraction NRE EJ[scenarios]=

extraction coal EJ[scenarios]+extraction conv gas without GTL EJ[scenarios
]+extraction conv oil EJ[scenarios]+extraction unconv gas EJ[scenarios]+extraction unconv oil EJ
[scenarios]+extraction uranium EJ[scenarios]

Units: EJ/Year

Annual total extraction of non-renewable energy resources.

TPE from RES EJ[scenarios]=

PE Elec generation from RES EJ[scenarios]+"PE supply RES non-Elec EJ"[scenarios
]

Units: EJ/Year

Total primary energy supply from all RES.

TPED by sector EJ[scenarios]=

Total FE Elec demand EJ[scenarios]+Total gen losses demand for Elec EJ[scenarios
]+PE traditional biomass EJ[scenarios]+PE demand Transport after policies EJ
[scenarios]+"PE demand Ind after RES+efficiency EJ"[scenarios]+"PE demand Build after RES+efficiency EJ"
[scenarios]+"Additional PE production of CTL+GTL for liquids"
[scenarios]

Units: EJ/Year

Total primary energy demand by sector after policies.

TPES EJ[scenarios]=

Total extraction NRE EJ[scenarios]+TPE from RES EJ[scenarios]

Units: EJ/Year

Total Primary Energy Supply.

TPES Mtoe[scenarios]=

TPES EJ[scenarios]*MToe per EJ

Units: MToe/Year

Total Primary Energy Supply.

Year scarcity TPE[scenarios]=

IF THEN ELSE(abundance TPE[scenarios]>0.95, 0, Time)

Units: Year

Year when the parameter abundance falls below 0.95, i.e. year when scarcity starts.

35. ABUND – Abundances by sector

abundance IB[scenarios]=

IF THEN ELSE(PES for IB EJ[scenarios]>PE demand for IB after RES EJ[scenarios], 1, 1-((PE demand for IB after RES EJ[scenarios]-PES for IB EJ[scenarios])/PE demand for IB after RES EJ[scenarios]))

Units: Dmnl

The parameter abundance varies between (1;0). Abundance=1 while the supply covers the demand; the closest to 0 indicates a higher divergence between supply and demand.

abundance transport[scenarios]=

IF THEN ELSE(PES for Transp EJ[scenarios]>PE demand Transport after policies EJ [scenarios], 1, 1-((PE demand Transport after policies EJ[scenarios]-PES for Transp EJ [scenarios])/PE demand Transport after policies EJ[scenarios]))

Units: Dmnl

The parameter abundance varies between (1;0). Abundance=1 while the supply covers the demand; the closest to 0 indicates a higher divergence between supply and demand.

check IB[scenarios]=

(PE demand for IB after RES EJ[scenarios]-PES for IB EJ[scenarios])/PES for IB EJ [scenarios]

Units: Dmnl

If=1: demand=supply. If>0: demand>supply. If<0: demand<supply. Variable to avoid energy oversupply caused by exogenously driven policies.

check Transp[scenarios]=

(PE demand Transport after policies EJ[scenarios]-PES for Transp EJ[scenarios

])/PES for Transp EJ[scenarios]

Units: Dmnl

If=1: demand=supply. If>0: demand>supply. If<0: demand<supply.

Variable to avoid energy oversupply caused by exogenously driven policies.

"constrain IB exogenous growth?"[scenarios]=

IF THEN ELSE(check IB[scenarios]>-0.05 ,1 ,check IB[scenarios])

Units: Dmnl

If negative, there is oversupply of energy in the IB sector.

This variable is used to constrain the exogenous growth of exogenously-driven policies. We use the value 0.05 instead of 0 to help to converge the model.

current trends demand Elec for Transp[scenarios]=

PE demand for Transport initial EJ[scenarios]*Current trends electric transport share [scenarios]

Units: EJ/Year

Current trends of Demand of electricity for Transportation (EJ).

We assume that the share of current TPE demand of transport covered by electricity (excepting alternative policies) is maintained constant in the future. Since we extrapolate the current trends, the electricity consumption is not increased assuming that current trends are already included in the electricity consumption trend.

Increase Elec demand for Transp EJ[scenarios]=

increase Elec demand for Transp TWh[scenarios]*EJ per TWh

Units: EJ/Year

Additional electricity demand due to the shift alternative transport (BEV & HEV).

Liquids production for IB EJ[scenarios]=

Liquids extraction EJ[scenarios]*share liquids for IB[scenarios]

Units: EJ/Year

Annual liquids production for Industrial&Buildings sector.

Oil liquids saved by biofuels EJ[scenarios]=

PEavail total biofuels production EJ[scenarios]

Units: EJ/Year

Oil liquids saved by biofuels.

PE coal for IB EJ[scenarios]=

extraction coal without CTL EJ[scenarios]*share coal for IB[scenarios]

Units: EJ/Year

PE demand for IB after RES EJ[scenarios]=

"PE demand Ind after RES+efficiency EJ"[scenarios]+"PE demand Build after RES+efficiency EJ"
[scenarios]

Units: EJ/Year

Primary energy demand for Industry and Buildings sector after
policies.

PE demand Transport after policies EJ[scenarios]=

demand gas for Transp EJ[scenarios]+real PE demand of liquids for Transp EJ
[scenarios]

Units: EJ/Year

Primary energy demand for Transportation after policies
(excluding electricity).

PE gas extraction for Transp EJ[scenarios]=

total gas extraction without GTL[scenarios]*share gas for Transp[scenarios
]

Units: EJ/Year

Primary energy gas extraction (excluding GTL) for Transportation.

PE liquids production for Transp EJ[scenarios]=

Liquids extraction EJ[scenarios]*share liquids for Transp[scenarios]

Units: EJ/Year

Total liquids produced for covering the energy requirements of
the Transportation sector.

PES for IB EJ[scenarios]=

PE coal for IB EJ[scenarios]+Total gas extraction for IB EJ[scenarios]+Liquids production for IB EJ [scenarios]+thermal RES supply[scenarios]

Units: EJ/Year

Primary energy supply for Industry and Buildings sector.

PES for Transp EJ[scenarios]=

PE gas extraction for Transp EJ[scenarios]+PE liquids production for Transp EJ [scenarios]+current trends demand Elec for Transp[scenarios]

Units: EJ/Year

Primary energy supply extraction for the Transportation sector (excluding electricity).

thermal RES supply[scenarios]=

thermal RES supply for Ind[scenarios]+thermal RES supply for Build[scenarios]

Units: EJ

Total thermal RES supply (Industry + Buildings).

Total gas extraction for IB EJ[scenarios]=

total gas extraction without GTL[scenarios]*share gas for IB[scenarios]

Units: EJ/Year

Total gas extraction for the Industtry & Buildings sector.

Year scarcity IB[scenarios]=

IF THEN ELSE(abundance IB[scenarios]>0.95, 0, Time)

Units: Year

Year when the parameter abundance falls below 0.95, i.e. year when scarcity starts.

Year scarcity Transp[scenarios]=

IF THEN ELSE(abundance transport[scenarios]>0.95, 0, Time)

Units: Year

Year when the parameter abundance falls below 0.95, i.e. year when scarcity starts.

36. IMPACTS – RES land-use

Global arable land=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C70')

Units: MHa

Current global arable land: 1526 MHa (FAOSTAT).

Land compet required dedicated crops for biofuels[scenarios]=

Land compet biofuels 2gen Mha[scenarios]+Land compet biofuels 3gen Mha[scenarios
]

Units: MHa

Land requirements for crops for biofuels 2nd and 3rd generation
(in land competing with other uses).

Land required biofuels land marg[scenarios]=

PEavail biofuels land marg EJ[scenarios]*Land occupation ratio biofuels marg land
/Conv efficiency from NPP to biofuels

Units: MHa/Year

Marginal lands occupied by biofuels.

Share land compet biofuels[scenarios]=

Land compet required dedicated crops for biofuels[scenarios]/Global arable land

Units: **undefined**

Share of global arable land required by dedicated crops for
biofuels (in land competition).

share land RES land compet vs arable[scenarios]=

(Land compet required dedicated crops for biofuels[scenarios]+surface MHa solar
[scenarios])/Global arable land

Units: Dmnl

Land requirements for RES that compete with other land-uses
(solar on land and biofuels on land competition) as a share of
the global arable land.

share land total RES vs arable[scenarios]=

Total land requirements renew Mha[scenarios]/Global arable land

Units: MHa

Land requirements for all RES as a share of the global arable
land.

share land total RES vs urban surface[scenarios]=

Total land requirements renew Mha[scenarios]/urban surface 2008

Units: **undefined**

Land requirements for all RES as a share of the global urban

land.

surface MHa solar[scenarios]=

solar TWe[scenarios]/power density solar

Units: MHa

Surface required to produce "solar TWe".

surface onshore wind[scenarios]=

onshore wind TWe[scenarios]/power density onshore wind

Units: MHa

Surface required to produce "onshore wind TWe".

Total land requirements renew Mha[scenarios]=

surface MHa solar[scenarios]+surface onshore wind[scenarios]+Land compet required dedicated crops for biofuels

[scenarios]+Land required biofuels land marg[scenarios]

Units: MHa

Land required for RES power plants and total bioenergy (land

competition + marginal lands).

urban surface 2008=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C71')

Units: MHa

Area occupied by human settlement and infraestructures. This

area is roughly 200-400MHa (Wackernagel et al., 2002; WWF, 2008;

Young, 1999).

37. IMPACTS – CO2 emissions from electric RES

GtCO2e electric renewables[scenarios]=

"GtCO2e geot-elec"[scenarios]+GtCO2e hydro[scenarios]+GtCO2e oceanic[scenarios

]+GtCO2e solar[scenarios]+GtCO2e onshore wind[scenarios]+GtCO2e offshore wind

[scenarios]

Units: GTCO2e/Year

Annual CO2 emissions of electric RES excepting biomass-related emissions.

"GtCO2e geot-elec"[scenarios]=

FE Elec generation from geot TWh[scenarios]*GTCO2e per gCO2e*"gCO2e per KWh geot-elec" *kWh per TWh

Units: GTCO2e/Year

Annual CO2e emissions.

GtCO2e hydro[scenarios]=

FE Elec generation from hydro TWh[scenarios]*gCO2e per kWh hydro*GTCO2e per gCO2e *kWh per TWh

Units: GTCO2e/Year

Annual CO2e emissions.

GtCO2e oceanic[scenarios]=

FE Elec generation from oceanic TWh[scenarios]*gCO2e per KWh oceanic*GTCO2e per gCO2e *kWh per TWh

Units: GTCO2e/Year

Annual CO2e emissions.

GtCO2e offshore wind[scenarios]=

FE Elec generation from offshore wind TWh[scenarios]*gCO2e per KWh offshore wind *GTCO2e per gCO2e*kWh per TWh

Units: GTCO2e/Year

Annual CO2e emissions.

GtCO2e onshore wind[scenarios]=

FE Elec generation from onshore wind TWh[scenarios]*gCO2e per KWh onshore wind *GTCO2e per gCO2e*kWh per TWh

Units: GTCO2e/Year

Annual CO2e emissions.

GtCO2e solar[scenarios]=

FE Elec generation from solar TWh[scenarios]*gCO2e per KWh solar*GTCO2e per gCO2e *kWh per TWh

Units: GTCO2e

Annual CO2e emissions.

38. IMPACTS – Total CO2 emissions

activate Affores program[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'B65')

activate Affores program[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'B65')

activate Affores program[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'B65')

activate Affores program[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'B65')

activate Affores program[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'B65')

activate Affores program[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'B65')

Units: Dmnl

1. Activated. 2. No.

Adapt emissions shale oil[scenarios]=

IF THEN ELSE(Time<2050, 0.001+(0.15-0.001)*(Time dmnl[scenarios](Time)-2000
)/50, IF THEN ELSE(Time<2100, 0.15+(0.72-0.15)*(Time dmnl[scenarios](Time)
-2050)/50, 0.72))

Units: Dmnl

Shale oil emissions are 6,14tCO2/toe vs 3,84 for unconventional
oil. Since we have unconventional oils in an aggregated manner,
this functions corrects these emissions assuming that shale oil
would follow the share in relation to the total unconventional
oil as estimated by [Mohr&Evans2010](Low Case) for 2050 and 2100
(linear interpolation)

Adapt emissions unconv gas dobro[scenarios]=

IF THEN ELSE(Time<2050, 0.01+(0.22-0.01)*(Time dmnl[scenarios](Time)-2000
)/50, IF THEN ELSE(Time<2100, 0.22+(0.6-0.22)*(Time dmnl[scenarios](Time)-
2050)/50, 0.6))

Units: Dmnl

Unconventional gas emissions are 3,53 tCO2/toe vs 2,35 for
conventional. Since we have all natural gas modeled in an
aggregated manner, this function corrects these emissions
assuming that unconventional gas would follow the share un
relation to natural gas as estimated by [Mohr&Evans2011](BG) for
2050 and 2100 (linear interpolation).

Adapt emissions unconv oil[scenarios]=
IF THEN ELSE(Time<2050,0.0538+(0.3441-0.0538)*(Time-2012)/38,IF THEN ELSE(
Time<2100,0.3441+(0.9789-0.3441)*(Time-2050)/50,0.9789))
Units: Dmnl
Different unconventional oils have different CO2 emissions
factors. Since all unconventional oils are aggregated in the
model, we assume a fixed share for different categories (see
Technical Report).

Afforestation program 2020:INTERPOLATE::=
GET XLS DATA('inputs.xlsx', 'Parameters', '125', 'C126')
Units: MtC/Year
Afforestation program from 2020 following [Nilsson 1995] (time
to inverse the deforestation trend).

Afforestation program 2020 GtCO2[scenarios]=
Afforestation program 2020*activate Affores program[scenarios]/(C per CO2*
Mt per Gt)
Units: GtCO2/Year
Annual emissions captured by the afforestation program.

BioE CO2 emissions[scenarios]=
GtCO2 per Mtoe conv gas*(Oil saved by biofuels MToe[scenarios]+0*(PE BioW for Elec generation Mtoe
[scenarios
]+PE traditional biomass EJ[scenarios]*MToe per EJ))
Units: GTCO2e/Year
CO2 emissions from biomass. We assume that biofuels have an
emission intensity similar to natural gas (due to ILUCs, see
Technical Report), and for the rest (traditional biomass,
biomass for electricity and biomass for heat) we asssume that

the carbon balance is null.

C per CO2=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C11')

Units: GtC/GTCO2e

1 kg of CO2 contains 3/11 of carbon.

carbon budget=

1000

Units: GtC

Carbon budget, the amount of carbon dioxide emissions we can emit while still having a likely chance of limiting global temperature rise to 2 degrees Celsius above pre-industrial levels (IPCC 2014).

Carbon emissions GtC[scenarios]=

CO2 emissions GtCO2[scenarios]*C per CO2

Units: GtC/Year

Total anual carbon emissions.

CO2 emissions GtCO2[scenarios]=

Fossil fuel emissions GtCO2[scenarios]+Land use change emissions GtCO2+BioE CO2 emissions [scenarios]+GtCO2e electric renewables [scenarios]+(GtCO2e nuclear[scenarios])-Afforestation program 2020 GtCO2[scenarios]

Units: GTCO2e/Year

Total annual CO2 emissions. Original unit: "mill Tn CO2"

Cumulative emissions to 1990=

343.82

Units: GtC

Cumulative emissions 1751-1990 due to carbon emissions from fossil fuel consumption, cement production and land-use changes. Data from CDIAC and World Resources Institute.

emissions coal without CTL GtCO2[scenarios]=

extraction coal without CTL EJ[scenarios]*GtCO2 per Mtoe coal*MToe per EJ

Units: GTCO2e/Year

Emissions from coal withoug accounting for CTL-related emissions.

emissions conv gas without GTL[scenarios]=

IF THEN ELSE("separate conv and unconv gas?"[scenarios]=1,

extraction conv gas without GTL EJ[scenarios]*GtCO2 per Mtoe conv gas*MToe per EJ

,

(1-Adapt emissions unconv gas dobro[scenarios])*extraction conv gas without GTL EJ [scenarios]*GtCO2 per Mtoe conv gas*MToe per EJ+Adapt emissions unconv gas dobro [scenarios]*extraction conv gas without GTL EJ[scenarios]*GtCO2 per Mtoe unconv gas *MToe per EJ)

Units: GTCO2e/Year

CO2 emissions from conventional gas (withouth GTL) when the gas extraction is disaggregated in conventional and unconventional resource, and CO2 emissions from total gas when the extraction is aggregated.

emissions conv oil[scenarios]=

IF THEN ELSE("separate conv and unconv oil?"[scenarios]=1,extraction conv oil Mtoe [scenarios]*GtCO2 per Mtoe conv oil,(1-Adapt emissions unconv oil[scenarios])*extraction conv oil Mtoe[scenarios]*GtCO2 per Mtoe conv oil+Adapt emissions unconv oil [scenarios]*extraction conv oil Mtoe[scenarios]*GtCO2 per Mtoe unconv oil+ (GtCO2 per Mtoe unconv oil+(GtCO2 per Mtoe shale oil-GtCO2 per Mtoe unconv oil)*Adapt emissions shale oil[scenarios]))

Units: GTCO2e/Year

CO2 emissions from conventional oil when the oil extraction is disaggregated in conventional and unconventional resource, and CO2 emissions from total oil when the extraction is aggregated.

emissions CTL GtCO2[scenarios]=

GtCO2 per Mtoe CTL*extraction coal for CTL EJ[scenarios]*MToe per EJ

Units: GTCO2e/Year

Emissions associated to CTL production.

emissions GTL GtCO2[scenarios]=

extraction conv gas for GTL EJ[scenarios]*GtCO2 per Mtoe GTL*MToe per EJ

Units: GTCO2e/Year

Emissions associated to GTL production.

emissions unconv gas[scenarios]=

GtCO2 per Mtoe unconv gas*extraction unconv gas Mtoe[scenarios]

Units: GTCO2e/Year

CO2 emissions from unconventional gas when the oil extraction is

disaggregated in conventional and unconventional resource.

emissions unconv oil[scenarios]=

IF THEN ELSE(Time<2013, extraction unconv oil Mtoe[scenarios]*(GtCO2 per Mtoe unconv oil

+(GtCO2 per Mtoe shale oil-GtCO2 per Mtoe unconv oil)*Adapt emissions shale oil

[scenarios]),IF THEN ELSE("separate conv and unconv oil?"[scenarios]=1,

extraction unconv oil Mtoe[scenarios]*(GtCO2 per Mtoe unconv oil+(GtCO2 per Mtoe shale oil

-GtCO2 per Mtoe unconv oil)*Adapt emissions shale oil[scenarios]),0))

Units: GTCO2e/Year

CO2 emissions from unconventional oil when the oil extraction is

disaggregated in conventional and unconventional resource.

extraction coal for CTL EJ[scenarios]=

demand coal for CTL EJ[scenarios]

Units: EJ/Year

Extraction of coal for CTL. CTL demand is given priority over

other uses since it is an exogenous assumption depending on the

scenario.

extraction coal without CTL EJ[scenarios]=

MAX(extraction coal EJ[scenarios]-extraction coal for CTL EJ[scenarios], 0

)

Units: EJ/Year

Extraction of conventional gas excepting the resource used to

produce GTL.

extraction conv gas for GTL EJ[scenarios]=

demand gas for GTL EJ[scenarios]

Units: EJ/Year

Extraction of conventional gas for GTL. GTL demand is given

priority over other uses of since it is an exogenous assumption depending on the scenario.

extraction conv gas without GTL EJ[scenarios]=

MAX(extraction conv gas EJ[scenarios]-extraction conv gas for GTL EJ[scenarios
], 0)

Units: EJ

Extraction of conventional gas excepting the resource used to produce GTL.

extraction conv oil Mtoe[scenarios]=

extraction conv oil EJ[scenarios]*MToe per EJ

Units: MToe/Year

Annual extraction of unconventional oil.

extraction unconv gas Mtoe[scenarios]=

extraction unconv gas EJ[scenarios]*MToe per EJ

Units: MToe/Year

extraction unconv oil Mtoe[scenarios]=

extraction unconv oil EJ[scenarios]*MToe per EJ

Units: MToe/Year

Annual extraction of unconventional oil.

Fossil fuel emissions GtCO2[scenarios]=

emissions conv gas without GTL[scenarios]+emissions unconv gas[scenarios]+
emissions GTL GtCO2
[scenarios]+emissions conv oil[scenarios]+emissions unconv oil[scenarios]+
emissions coal without CTL GtCO2[scenarios]+emissions CTL GtCO2[scenarios]

Units: GTCO2e/Year

Total CO2 emissions from fossil fuels.

GtCO2 per Mtoe coal=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C91')

Units: GTCO2e/MToe

3.96 tCO2/toe [BP2012] y [Farrell and Brandt, 2006]

GtCO2 per Mtoe conv gas=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C92')

Units: GTCO2e/MToe

2.35 tCO2/toe [BP2012] y [Farrell and Brandt, 2006]

GtCO2 per Mtoe conv oil=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C93')

Units: GTCO2e/MToe

3.07 tCO2/toe [BP2012] y [Farrell and Brandt, 2006]

GtCO2 per Mtoe CTL=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C89')

Units: GTCO2e/MToe

CO2 emissions coefficient of CTL.

GtCO2 per Mtoe GTL=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C90')

Units: GTCO2e/MToe

CO2 emissions coefficient of GTL.

GtCO2 per Mtoe shale oil=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C96')

Units: GTCO2e/MToe

6.14 tCO2/toe [BP2012] y [Farrell and Brandt, 2006]

GtCO2 per Mtoe unconv gas=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C94')

Units: GTCO2e/MToe

3.53 tCO2/toe [BP2012] y [Farrell and Brandt, 2006]

GtCO2 per Mtoe unconv oil=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C95')

Units: GTCO2e/MToe

3.84 tCO2/toe [BP2012] y [Farrell and Brandt, 2006]

GtCO2e electric renewables[scenarios]=

"GtCO2e geot-elec"[scenarios]+GtCO2e hydro[scenarios]+GtCO2e oceanic[scenarios
]+GtCO2e solar[scenarios]+GtCO2e onshore wind[scenarios]+GtCO2e offshore wind

[scenarios]

Units: GTCO2e/Year

Annual CO2 emissions of electric RES excepting biomass-related emissions.

GtCO2e nuclear[scenarios]=

FE nuclear Elec generation TWh[scenarios]*gCO2e per kWh nuclear*GTCO2e per gCO2e *kWh per TWh

Units: GTCO2e/Year

Land use change emissions GtCO2:INTERPOLATE::=

GET XLS DATA('inputs.xlsx', 'Parameters', '102', 'C103')

Units: GtCO2/Year

[DICE-2013R] Land-use change emissions. Cte at 2010 level for the period 1990-2100 as first approximation.

Mt per Gt=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C21')

Units: **undefined**

Conversion from Mega to Giga (1000 M = 1 G).

MToe per EJ=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C6')

Units: MToe/EJ

Unit conversion (1000 Mtoe=41.868 EJ)

new C GtC[scenarios]=

Carbon emissions GtC[scenarios]

Units: GtC/Year

Annual carbon emissions.

Oil saved by biofuels MToe[scenarios]=

Oil liquids saved by biofuels EJ[scenarios]*MToe per EJ

Units: MToe/Year

Oil saved by biofuels.

PE BioW for Elec generation Mtoe[scenarios]=

PE BioW for Elec generation EJ[scenarios]*MToe per EJ

Units: MToe/Year

Annual primary energy to generate electricity (Direct Equivalent Method).

PE traditional biomass EJ[scenarios]=

Population[scenarios]*share global pop dependent on trad biomass[scenarios]*PEpc consumption people depending on trad biomass

Units: EJ/Year

Annual primary energy consumption of traditional biomass.

"separate conv and unconv gas?"[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C83')

"separate conv and unconv gas?"[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C83')

"separate conv and unconv gas?"[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C83')

"separate conv and unconv gas?"[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C83')

"separate conv and unconv gas?"[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C83')

"separate conv and unconv gas?"[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C83')

Units: Dmnl

Switch to disaggregate between conventional and unconventional fuel: "1" = disaggregation, "0" = conv+unconv aggregated (all the gas flows then through the right side of this view, i.e. the "conventional gas" modelling side).

"separate conv and unconv oil?"[BAU]=

GET XLS CONSTANTS('inputs.xlsx', 'BAU', 'C67')

"separate conv and unconv oil?"[SCEN1]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN1', 'C67')

"separate conv and unconv oil?"[SCEN2]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN2', 'C67')

"separate conv and unconv oil?"[SCEN3]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN3', 'C67')

"separate conv and unconv oil?"[SCEN4]=

GET XLS CONSTANTS('inputs.xlsx', 'SCEN4', 'C67')

"separate conv and unconv oil?"[User defined]=

GET XLS CONSTANTS('inputs.xlsx', 'User defined', 'C67')

Units: Dmnl

Switch to disaggregate between conventional and unconventional fuel: "1" = disaggregation, "0" = conv+unconv aggregated (all the oil flows then through the right side of this view, i.e. the "conventional oil" modelling side).

Time dmnl[scenarios](

[(1990,1990)-(2100,2100)],(1990,1990),(1991,1991),(1992,1992),(1993,1993),(1994,1994),(1995,1995),(1996,1996),(1997,1997),(1998,1998),(1999,1999),(2000,2000),(2001,2001),(2002,2002),(2003,2003),(2004,2004),(2005,2005),(2006,2006),(2007,2007),(2008,2008),(2009,2009),(2010,2010),(2011,2011),(2012,2012),(2013,2013),(2014,2014),(2015,2015),(2016,2016),(2017,2017),(2018,2018),(2019,2019),(2020,2020),(2021,2021),(2022,2022),(2023,2023),(2024,2024),(2025,2025),(2026,2026),(2027,2027),(2028,2028),(2029,2029),(2030,2030),(2031,2031),(2032,2032),(2033,2033),(2034,2034),(2035,2035),(2036,2036),(2037,2037),(2038,2038),(2039,2039),(2040,2040),(2041,2041),(2042,2042),(2043,2043),(2044,2044),(2045,2045),(2046,2046),(2047,2047),(2048,2048),(2049,2049),(2050,2050),(2051,2051),(2052,2052),(2053,2053),(2054,2054),(2055,2055),(2056,2056),(2057,2057),(2058,2058),(2059,2059),(2060,2060),(2061,2061),(2062,2062),(2063,2063),(2064,2064),(2065,2065),(2066,2066),(2067,2067),(2068,2068),(2069,2069),(2070,2070),(2071,2071),(2072,2072),(2073,2073),(2074,2074),(2075,2075),(2076,2076),(2077,2077),(2078,2078),(2079,2079),(2080,2080),(2081,2081),(2082,2082),(2083,2083),(2084,2084),(2085,2085),(2086,2086),(2087,2087),(2088,2088),(2089,2089),(2090,2090),(2091,2091),(2092,2092),(2093,2093),(2094,2094),(2095,2095),(2096,2096),(2097,2097),(2098,2098),(2099,2099),(2100,2100))

Units: Dmnl

Vector that assigns for every year the number of that same year.

TIME STEP = 0.25

Units: Year [0,?]

The time step for the simulation.

Total cumulative emissions GtC[scenarios]= INTEG (

new C GtC[scenarios],

Cumulative emissions to 1990)

Units: GtC

Total cumulative emissions.

Total cumulative emissions GtCO2[scenarios]=

Total cumulative emissions GtC[scenarios]/C per CO2

Units: GtCO2

Total cumulative emissions.

39. IMPACTS – Carbon cycle & climate

A UO Heat Cap=

1/Climate equation coefficient for upper level

Units: watt*Year/DegreesC/(meter*meter) [8,400]

[Fiddaman] Atmosphere & Upper Ocean Heat Capacity per Unit Area

[1/R1] (W-yr/m^2/degrees C). Note: equals 1/0.0226 [DICE-2013R]

c1 Climate equation coefficient for upper level /0.098 /

Atmos UOcean Temp[scenarios]= INTEG (

Chg A UO Temp[scenarios],

init Atmos UOcean Temp)

Units: DegreesC

Temperature of the Atmosphere and Upper Ocean [T] (degrees C)

[Cowles, pg. 24] Historical data from:

http://cdiac.ornl.gov/ftp/trends/temp/hansen/gl_land_ocean.txt

Average Atmos Retention[scenarios]=

(CO2 Net Emiss[scenarios]-CO2 Storage[scenarios])/Total Carbon Emisions[scenarios

]

Units: Dmnl

Average atmospheric retention.

C per CO2=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C11')

Units: GtC/GTCO2e

1 kg of CO2 contains 3/11 of carbon.

Chg A UO Temp[scenarios]=

(Total Radiative Forcing[scenarios]-Feedback Cooling[scenarios]-Heat Transfer [scenarios])/A UO Heat Cap

Units: DegreesC/Year

Change in the Atmosphere & Upper Ocean Temperature (degrees C/yr) [Cowles, pg. 27]

Chg DO Temp[scenarios]=

Heat Transfer[scenarios]/DO Heat Cap

Units: DegreesC/Year

Change in the Deep Ocean Temperature (degrees C/yr) [Cowles, pg. 30]

Climate equation coefficient for upper level=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C118')

Units: **undefined** [8,400]

[Fiddaman] Atmosphere & Upper Ocean Heat Capacity per Unit Area [1/R1] (W-yr/m^2/degrees C). Note: equals 1/0.0226 [DICE-2013R]

c1 Climate equation coefficient for upper level /0.098 /

Climate Feedback Param=

CO2 Rad Force Coeff/Climate Sensitivity

Units: watt/meter/meter/DegreesC

Climate Feedback Parameter [lambda] (W-m^2/degree C) The crucial climate sensitivity parameter - determines gain of feedback from temperature increase and thus determines equilibrium response to forcing. The Schneider-Thompson 2-stock model uses 1.33 [Cowles, Table III-B1]. [Managing Global Commons, pg. 21]

Climate Sensitivity=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C115')

Units: DegreesC

[Fiddaman] Equilibrium temperature change in response to a 2xCO2 equivalent change in radiative forcing. /2.908 /. [DICE-2013R]

t2xco2 Equilibrium temp impact (ºC per doubling CO2) /2.9 /

CO2 emissions GtCO2[scenarios]=

Fossil fuel emissions GtCO2[scenarios]+Land use change emissions GtCO2+BioE CO2 emissions

[scenarios]+GtCO2e electric renewables

[scenarios]+(GtCO2e nuclear[scenarios])-Afforestation program 2020 GtCO2[scenarios

]

Units: GTCO2e/Year

Total annual CO2 emissions. Original unit: "mill Tn CO2"

CO2 in Atmos[scenarios]= INTEG (

CO2 Net Emiss[scenarios] - CO2 Storage[scenarios],

init CO2 in Atmos)

Units: TonC

CO2 in atmosphere.

CO2 Net Emiss[scenarios]=

Marginal Atmos Retention*Total Carbon Emisions[scenarios]

Units: TonC/Year

CO2 emissions less short-run uptake (to mixed ocean layer).

"CO2 ppm concentrations WoLiM 1.1"[scenarios]=

CO2 in Atmos[scenarios]/(2.13*1e+009)

Units: ppm

1 part per million of atmospheric CO2 is equivalent to 2.13

Gigatonnes Carbon. Historical Mauna Loa CO2 Record:

ftp://ftp.cmdl.noaa.gov/products/trends/co2/co2_mm_mlo.txt

CO2 Rad Force Coeff=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C114')

Units: watt/meter/meter

[Fiddaman] Coefficient of Radiative Forcing from CO2 (W/m^2).

Coeff. of additional surface warming from accumulation of CO2.

/4.1 / [DICE-2013R] fco22x Forcings of equilibrium CO2 doubling

(Wm-2) /3.8 /

CO2 Rad Forcing[scenarios]=

CO2 Rad Force Coeff*LOG(CO2 in Atmos[scenarios]/Preindustrial CO2,2)

Units: watt/meter/meter

Radiative Forcing from CO2 [F(t)] (W/m^2) Additional surface
warming from accumulation of CO2. [Cowles, pg. 22]

CO2 Storage[scenarios]=
(CO2 in Atmos[scenarios]-Preindustrial CO2)*Rate of CO2 Transfer
Units: TonC/Year
CO2 removal from the atmosphere and storage by long-term
processes.

Deep Ocean Temp[scenarios]= INTEG (
Chg DO Temp[scenarios],
init Deep Ocean Temp)
Units: DegreesC
Temperature of the Deep Ocean [T*] (degrees C) [Cowles, pg. 24]

DO Heat Cap = Heat Capacity Ratio*Heat Trans Coeff
Units: watt*Year/DegreesC/meter/meter
Deep Ocean Heat Capacity per Unit Area [R2] (W-yr/m^2/degrees C)
Note: Managing Global Commons uses .44*Heat_Trans_Coeff = 220;
Cowles report uses 223.7 (page 30). [Managing Global Commons,
pg. 21]

Feedback Cooling[scenarios]=
Atmos UOcean Temp[scenarios]*Climate Feedback Param
Units: watt/meter/meter
Heat loss of the atmosphere/upper ocean system from feedback
effects of warming (i.e. increased blackbody radiation).
[Cowles, pg. 27]

Heat Capacity Ratio=
GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C117')
Units: watt/(meter*meter*DegreesC) [0.1,1]
[Fidddaman] Ratio of Thermal Capacity of Deep Ocean to Heat
Transfer Time Constant [R2/Tau12]. /0.44 / [DICE-2013R] c3
Transfer coefficient upper to lower stratum /0.088 /

Heat Trans Coeff=

1/Transfer coefficient for lower level

Units: Year [100,4000]

[Fiddaman] Heat Transfer Coefficient [tau12] (years).

Coefficient of heat transfer between the atmosphere & upper ocean and the deep ocean. /500 / [DICE-2013R] 1/c4; c4 Transfer coefficient for lower level /0.025 /

Heat Transfer[scenarios]=

Temp Diff[scenarios]*DO Heat Cap/Heat Trans Coeff

Units: watt/meter/meter

Heat Transfer from the Atmosphere & Upper Ocean to the Deep Ocean

init Atmos UOcean Temp=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C119')

Units: DegreesC

Global Annual Temperature Anomaly (Land + Ocean) in 1990 from

NASA GISS Surface Temperature (GISTEMP): +0.43 ºC. 5-year average: +0.35 ºC. http://cdiac.ornl.gov/ftp/trends/temp/hansen/gl_land_ocean.txt [DICE-1994] Initial Temperature of the Atmosphere and Upper Ocean [T] (degrees C) 1965 [Cowles, pg. 24] /0.2 / [DICE-2013R] tatm0 Initial atmospheric temp change (degrees C from 1900) 2010 /0.80 /

init CO2 in Atmos=

init CO2 in Atmos ppm*ppm per GtC*t per Gt

Units: TonC

Initial CO2 in atmosphere. [DICE-1994] Initial Greenhouse Gases

in Atmosphere 1965 [M(t)] (tC equivalent). [Cowles, pg. 21] /6.77e+011 / [DICE-2013R] mat0: Initial concentration in atmosphere 2010 (GtC) /830.4 /

init CO2 in Atmos ppm=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C111')

Units: ppm

Initial CO2 in atmosphere. Historical Mauna Loa CO2 Record:

Average between 1st and last month of 1990 was:

(353.74+355.12)/2=354.43 ppm

ftp://ftp.cmdl.noaa.gov/products/trends/co2/co2_mm_mlo.txt

[DICE-1994] Initial Greenhouse Gases in Atmosphere 1965 [M(t)]

(tC equivalent). [Cowles, pg. 21] /6.77e+011 / [DICE-2013R]

mat0: Initial concentration in atmosphere 2010 (GtC) /830.4 /

init Deep Ocean Temp=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C120')

Units: DegreesC

[DICE-1994] Temperature of the Deep Ocean [T*] (degrees C).

[Cowles, pg. 24] 1965 /0.1 / [DICE-2013R] tocean0 Initial lower

stratum temp change 2010 (degrees C from 1990) /0.0068/

Marginal Atmos Retention=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C110')

Units: Dmnl

Marginal Atmospheric Retention Fraction. Fraction of Greenhouse

Gas Emissions which accumulate in the atmosphere.

one year=

1

Units: Year

Other GHG Rad Forcing:INTERPOLATE::=

GET XLS DATA('inputs.xlsx', 'Parameters', '102', 'C104')

Units: watt/(meter*meter)

Source: baseline scenario from DICE-2013R. "Estimates of future

impacts of aerosols have proven challenging, and the current

model uses estimates from the scenarios prepared for the Fifth

Assessment of the IPCC. The estimates in DICE-2013R are drawn

from the guidance for the “Representative Concentration

Pathways" (RCPs, see http://tntcat.iiasa.ac.at:8787/RcpDb/

dsd?ction=htmlpage&page=compare). The high path has

exceptionally high and unreasonable estimates of methane

forcings. The estimates here use the RCP 6.0 W/ m2

representative scenario, which is more consistent with the other

scenarios and with historical trends. These estimate non-CO2 forcings of 0.25 W/m2 in 2010 and 0.7 W/m2 in 2100. Non-CO2 forcings are small relative to estimated CO2 forcings, with 6.5 W/m2 of forcings from CO2 in 2100 in the DICE baseline projection." Nordhaus & Sztorc (2013).

ppm per GtC=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C19')

Units: (ppm*Year)/GtC

Conversion from ppm to GtC (1 ppm CO2 = 2.12 GtC).

pre industrial value ppm=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C20')

Units: ppm

Pre-industrial CO2 concentrations (275 ppm).

Preindustrial CO2=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C113')

Units: TonC

Preindustrial CO2 content of atmosphere. [DICE-2013R] 588 GtC

Rate of CO2 Transfer=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C112')

Units: 1/Year

Fractional rate of CO2 storage (corresponds to 120 year residence time). /0.008333 /

t per Gt=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C13')

Units: TonC/GtC

Conversion from tones to Gigatonnes of carbon.

Temp change 2C=

2

Units: DegreesC

Temperature change of 2C as reference.

Temp Diff[scenarios]=

Atmos UOcean Temp[scenarios]-Deep Ocean Temp[scenarios]

Units: DegreesC

Temperature Difference between Upper and Deep Ocean (degrees C)

Temperature change[scenarios]=

Atmos UOcean Temp[scenarios]

Units: DegreesC

It corresponds with the variable "Atmos UOcean Temp" that it is
not renamed in order to keep the original nomenclature from DICE.

Total Carbon Emisions[scenarios]=

CO2 emissions GtCO2[scenarios]*C per CO2*t per Gt

Units: TonC/Year

Total annual carbon emissions.

Total Radiative Forcing[scenarios]=

CO2 Rad Forcing[scenarios]+Other GHG Rad Forcing

Units: watt/meter/meter

Radiative Forcing from All GHGs (W/m^2) Additional surface
warming from accumulation of CO2 & CFCs. [Cowles, Sec. III.F]

Transfer coefficient for lower level=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C116')

Units: 1/Year [100,4000]

[Fiddaman] Heat Transfer Coefficient [tau12] (years).
Coefficient of heat transfer between the atmosphere & upper
ocean and the deep ocean. /500 / [DICE-2013R] 1/c4; c4 Transfer
coefficient for lower level /0.025 /

40. ENERGY INDICATORS

Average elec consumption per capita[scenarios]=

Total FE Elec generation TWh[scenarios]*kWh per TWh/Population[scenarios]

Units: kWh/people

Electricity consumption per capita (kWh per capita).

Average TPES per capita[scenarios]=

TPES EJ[scenarios]*GJ per EJ/Population[scenarios]

Units: GJ/(Year*people)

Average Total Primary Energy Supply per capita (GJ per capita).

"Average TPESpc (without trad biomass)"[scenarios]=

"TPES (without trad biomass)"[scenarios]*GJ per EJ/Pop not dependent on trad biomass [scenarios]

Units: GJ/people

Average per capita TPES without accounting for the energy supplied by traditional biomass. The population considered for estimating the average is not the global population, but the share of the population not relying on traditional biomass for covering their energy uses.

CO2 emissions GtCO2[scenarios]=

Fossil fuel emissions GtCO2[scenarios]+Land use change emissions GtCO2+BioE CO2 emissions [scenarios]+GtCO2e electric renewables [scenarios]+(GtCO2e nuclear[scenarios])-Afforestation program 2020 GtCO2[scenarios]

Units: GTCO2e/Year

Total annual CO2 emissions. Original unit: "mill Tn CO2"

CO2 emissions per capita[scenarios]=

CO2 emissions GtCO2[scenarios]*t per Gt/Population[scenarios]

Units: tCO2/person

CO2 emissions per capita.

GJ per EJ=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C14')

Units: Dmnl

Conversion from GJ to EJ (1 EJ = 1e9 GJ).

kWh per TWh=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C9')

Units: kWh/TWh

Conversion between kWh and TWh (1 TWh=1e9 kWh).

PE traditional biomass EJ[scenarios]=

Population[scenarios]*share global pop dependent on trad biomass[scenarios
]*PEpc consumption people depending on trad biomass

Units: EJ/Year

Annual primary energy consumption of traditional biomass.

Pop not dependent on trad biomass[scenarios]=

Population[scenarios]-Population dependent on trad biomass[scenarios]

Units: people

Global population not dependent on traditional biomass.

Population[scenarios]= INTEG (

pop variation[scenarios],

initial population)

Units: people

Population projection.

Population dependent on trad biomass[scenarios]=

Population[scenarios]*share global pop dependent on trad biomass[scenarios
]

Units: people

Population dependent on traditional biomass.

t per Gt=

GET XLS CONSTANTS('inputs.xlsx', 'Constants', 'C13')

Units: TonC/GtC

Conversion from tones to Gigatonnes of carbon.

Total FE Elec generation TWh[scenarios]=

FE Elec generation from NRE TWh[scenarios]+FE Elec generation from RES TWh
[scenarios]

Units: TWh/Year

Total final energy electricity generation (fossil fuels, nuclear
& renewables) (TWh).

TPED acceptable standard living=

GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C76')

Units: GJ/people

Approximative energy use value to fulfill the aceptable standard
of living (in terms of total primary energy use). Source:
(Goldemberg, 2011; Rao et al, 2014, WBGU,2003) cited in Arto et
al., (2016).

TPEFpc threshold high development=
GET XLS CONSTANTS('inputs.xlsx', 'Parameters', 'C75')
Units: GJ/people
Energy use threshold (in terms of total primary energy
footprint) found by Arto et al., (2016) to reach high
development (HDI>0.8).

"TPES (without trad biomass)"[scenarios]=
TPES EJ[scenarios]-PE traditional biomass EJ[scenarios]
Units: EJ
TPES without accounting for traditional biomass.

TPES EJ[scenarios]=
Total extraction NRE EJ[scenarios]+TPE from RES EJ[scenarios]
Units: EJ/Year
Total Primary Energy Supply.